U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-264 057

Effect of Automotive Parts on Vehicle and Engine Emissions Phase I. Original Equipment

Olson Labs, Inc, Anaheim, Calif

Prepared for

Environmental Protection Agency, Washington, D C [redacted]

Dec 76

EPA-340/2-76-001
December 1976

PB 264 057

EFFECT OF AUTOMOTIVE PARTS ON VEHICLE AND ENGINE EMISSIONS
PHASE I - ORIGINAL EQUIPMENT

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

U.S. Environmental Protection Agency
Mobile Source Enforcement Division
Technical Support Branch
Washington, D.C. 20460

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.
340/2-76-001

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
Effect of Automotive Parts on Vehicle and Engine Emissions
Phase I - Original Equipment

5. REPORT DATE
December 1976

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Richard R. Carlson

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Olson Laboratories, Inc.
421 E. Cerritos Avenue
Anaheim, CA 92805

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.
68-01-1957

12. SPONSORING AGENCY NAME AND ADDRESS
Environmental Protection Agency
Mobile Source Enforcement Division
401 M Street S.W.
Washington, D.C. 20460

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This final report documents the methodology and results of Phase I of the Investigation of the Effect of Automotive Parts on Vehicle and Engine Emissions. This study was performed for the Environmental Protection Agency, Office of Mobile Source Enforcement, under Contract No. 68-01-1957. The primary objective of this study was to identify engine and emission control system components which are critical in causing excessive emissions of one or more regulated pollutants. Phase I of the study investigated the emission-criticality of original equipment installed by the engine or vehicle manufacturers.

A computer model was developed to calculate and rank-order an index representing the criticality of each component type. Separate rankings were developed for HC, CO, NO_x and smoke (heavy-duty diesel engines) emissions and for pre-catalyst-equipped and catalyst-equipped vehicles. The index for each component type was calculated from the product of four factors representing the emission increase resulting from a component failure, the probability of component failure, the probability of component repair, and the sales volume of the component.

The values of these factors were established based on data obtained from a search of technical literature and engineering analysis of system and component design or operating characteristics. The study was performed without emission or performance testing. However, a series of tests on 25 of the most emission-critical components was recommended to develop or refine data on emission increase and symptoms of failure.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT
Unlimited

19. SECURITY CLASS *(This Report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES
260

22. PRICE

EPA Form 2220-1 (9-73)

EPA-340/2-76-001

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Prepared by

Richard R. Carlson

Olson Laboratories, Inc.
421 East Cerritos Avenue
Anaheim, California 92805

Contract No. 68-01-1957

EPA Project Officer:

Roy L. Reichlen

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Mobile Source Enforcement Division
Technical Support Branch
Washington, D.C. 20460

December 1976

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REPORT AVAILABILITY

Copies of this report are available from the Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711, or may be obtained at a nominal cost from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

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FOREWORD

The Clean Air Act requires that new vehicles and vehicle engines are to be warranteed by their manufacturer to be designed, built, and equipped so as to conform with applicable emission standards for their useful life. The Environmental Protection Agency, Office of Enforcement, Mobile Source Enforcement Division, is charged with enforcing compliance with applicable emission standards. Classes of vehicles or engines which are found to violate applicable standards during their useful life are subject to recall and corrective repair at the manufacturer's cost, providing that recommended maintenance and operating procedures had been followed by the vehicle owner.

However, surveillance test programs have shown that a relatively high proportion of in-use vehicles fail to comply with prescribed emission standards. These failures are generally related to malfunctions of specific components of the engine or emission control systems which may be defective, tampered with, or improperly adjusted. A key step in correcting these emission failures is to identify those components which are malfunctioning, how these malfunctions affect emissions, and how they can be detected. With this information, the EPA can then take the necessary enforcement action to ensure more effective compliance.

The objective of this study, therefore, was to assess the relative importance of engine and emission control components in causing excessive emissions in the in-service vehicle population. The importance of each component was measured by a criticality index based on factors representing:

- Impact on emissions of a single vehicle with a defective component
- Probability of defect occurrence
- Duration of defect occurrence
- Relative usage of each component.

ABSTRACT

This final report documents the methodology and results of Phase I of the Investigation of the Effect of Automotive Parts on Vehicle and Engine Emissions. This study was performed for the Environmental Protection Agency, Office of Mobile Source Enforcement, under Contract No. 68-01-1957. The primary objective of this study was to identify engine and emission control system components which are critical in causing excessive emissions of one or more regulated pollutants. Phase I of the study investigated the emission-criticality of original equipment installed by the engine or vehicle manufacturers.

A computer model was developed to calculate and rank-order an index representing the criticality of each component type. Separate rankings were developed for HC, CO, NO_x and smoke (heavy-duty diesel engines) emissions and for pre-catalyst-equipped and catalyst-equipped vehicles. The index for each component type was calculated from the product of four factors representing the emission increase resulting from a component failure, the probability of component failure, the probability of component repair, and the sales volume of the component.

The values of these factors were established based on data obtained from a search of technical literature and engineering analysis of system and component design or operating characteristics. The study was performed without emission or performance testing. However, a series of tests on 25 of the most emission-critical components was recommended to develop or refine data on emission increases and symptoms of failure.

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Section 1

INTRODUCTION AND SUMMARY

This report documents the results of Phase I of the Investigation of the Effect of Automotive Parts on Vehicle and Engine Emissions, EPA Contract 68-01-1957. Phase I of this study included all "original equipment" installed by or for the vehicle or engine manufacturers to ensure compliance with regulations issued under Title II of the Clean Air Act. For purposes of this study, original equipment (OEM) components also included replacement components available through the OEM dealer/service center network.

This section contains a summary of major findings, a statement of the problem, and a description of the study objectives, scope, and study plan. Section 2 discusses the literature search performed to obtain pertinent data and information. Section 3 describes emissions-related OEM components and systems. Section 4 discusses the emission-critical OEM components and the methodology used to rank them in order of their criticality. Section 5 discusses the detectability and diagnosis of failures in the most critical OEM components. Section 6 concludes this report with a recommended test protocol for 25 of the most critical OEM components.

1.1 SUMMARY OF MAJOR FINDINGS

The major findings of Phase I of this study for original equipment (OEM) components were the following:

- Literature clearly defining the effect on FTP emissions from specific component defects exists for only a few common components or adjustments.

- The ranking of emission-critical components is very sensitive to changes in the values of the input parameters representing the effect on emissions. (See Tables 1-1 and 1-2 for criticality lists for post-1975 models and all post-1972 models, respectively.)

- Specific emission control system component usage within certified engine families depends on such factors as transmission type, body style, and options such as air conditioning and heavy-duty cooling systems.

- The most emission-critical components for HC are typically ignition system components or components affecting air/fuel ratio. Catalysts are also critical to HC emissions from post-1975 model-year vehicles.

- The most emission-critical components for CO are typically carburetion components, although the air injection system, catalysts, and some ignition and mechanical components are also important.

Table 1-1. CRITICALITY INDEX RANKING - LATE MODELS*
(Automotive Parts Study - EPA Contract No. 68-01-1957)

HC	CO	NO_x	SMOKE (Diesel)	COMPOSITE
Spark Plugs	Choke Mechanism	EGR Valves	Valve Lifter/Spring	Spark Plugs
Ignition Wires	Power Valves	EGR Thermo Valve	Valve Seals	Ignition Wires
CAT Active Media	CAT Active Media	Thermo Vacuum Valve	Exhaust Valves	Choke Mechanism
Choke Mechanism	Metering Rods	EGR Vacuum Amplifier	MFI Valves	Power Valve
Power Valves	Float and Valve	Spark Delay Valve	Air Cleaner Element	Valve Lifter/Spring
Heat Riser	Vacuum Break Valve	EGR Hoses/Seals	Valve Cam Lobes	EGR Valves
EVAP Canister	Idle Adjustment	Ignition Timing Adj	Valve Guides	CAT Active Media
Cap	PCV Fresh/Air Filter	EGR Carb Spacer	Piston Rings	Valve Seals
Rotor	Air Cleaner Element	EGR Backpress Sensor	FI Throttle Valve	Exhaust Valve
Idle Adjustment	PCV Valve	EGR Speed/Trans Sen	FI Idle Adjustment	Metering Rods
TAC Vacuum Motor	AI Hoses	OSAC Vacuum Orifice	Head Gaskets	EGR Thermo Vacuum
TAC Vacuum Hoses	Spark Plugs	EGR Solenoid Valve	Camshafts	Float and Valve
PCV Fresh Air Filter	Vacuum Advance	EGR Time Delay	FI Pressure Sens/Reg	Heat Riser
PCV Valve	AI Bypass Diverter	ESC Speed Switch	Turbocharger	EVAP Canister
PCV Hoses	Valve Lifter/Spring	TCS Temp Switch		MFI Valves
EVAP Hose	Ignition Wires	TCS Vacuum Solenoid		Cap
Valve Lifter/Spring	AI Pump/Belts	TCS Trans Switch		Rotor
TAC Shroud	Valve Seals	TCS Thermo Valve		Thermo Vacuum Valve
TAC Thermostat	Exhaust Valves	ESC Elec Module		Vacuum Break Valve
Mag/Opt Triggers	FI Starting Valve	TCS Time Delay		Idle Adjustment
EVAP Fresh Air	Heat Riser	SCS Thermo Valve		TAC Vacuum Motor
AI Pump/Belts	Mechanical Advance	EGR Temp Switch		TAC Vacuum Hoses
AI Hoses	Elec Assist Choke	SCS Vacuum Solenoid		PCV Fresh Air Filter
Valve Seals	AI Manifold	SCS Speed Switch		Air Cleaner Element
Exhaust Valves	AI Check Valves	EFI Trigger Switch		EGR Vacuum Amplifier

*Late models for HC, CO, and NO_x include 1975 and subsequent model years.
Late models for smoke include 1974 and subsequent model years

Table 1-2. CRITICALITY INDEX RANKING - ALL 1972 AND LATER MODELS
(Automotive Parts Study - EPA Contract No. 68-01-1957)

HC	CO	NO_x	SMOKE (Diesel)	COMPOSITE
Spark Plugs	Choke Mechanism	EGR Valves	MFI Valves	Spark Plugs
Ignition Wires	Power Valves	EGR Thermo Valve	Valve Lifter/Springs	Ignition Wires
Valve Lifter/Springs	Valve Lifter/Springs	Spark Delay Valve	FI Throttle Valve	Choke Mechanism
Choke Mechanism	Float and Valve	EGR Vacuum Amplifier	FI Idle Adjustment	Power Valves
Power Valves	Valve Seals	Thermal Vacuum Valve	Valve Seals	MFI Valves
Valve Seals	Exhaust Valves	EGR Hoses/Seals	Exhaust Valves	Valve Lifter/Springs
Exhaust Valves	Metering Rods	TCS Temp Switch	FI Pres Sens/Reg	EGR Valve
Rotor	Air Cleaner Element	Ignition Timing Adj	Air Cleaner Element	Float and Valve
Cap	PCV Fresh Air Filter	TCS Trans Switch	Valve Cam Lobes	Exhaust Valves
CAT Active Media	Idle Adjustment	TCS Vacuum Solenoid	Valve Guides	Valve Seals
EVAP Canister	CAT Active Media	EGR Solenoid Valve	Piston Rings	Metering Rods
Heat Riser	PCV Fresh Air Filter	TCS Time Delay	Head Gaskets	EGR Thermal Valve
Points	Vacuum Break Valve	OSAC Vacuum Orifice	Camshafts	Air Cleaner Element
Idle Adjustment	AI Hoses	EGR Carb Spacer	Turbocharger	PCV Valve
TAC Vacuum Motor	Valve Cam Lobes	EGR Backpress Sensor		Rotor
TAC Vacuum Hoses	Valve Guides	TCS Thermal Valve		Cap
Coil	Piston Rings	EGR Time Delay		Idle Adjustment
Ballast Resistor	Vacuum Advance	EGR Temp Switch		Spark Delay Valve
PCV Valve	AI Pump/Belts	EGR Speed/Trans Sw		CAT Active Media
PCV Fresh Air Filter	Idle Stop Solenoid	OSAC Vacuum Bypass		PCV Fresh Air Filter
PCV Hoses	Spark Plugs	ESC Speed Switch		EVAP Canister
EVAP Hoses	AI Bypass/Diverter	ESC Elec Module		Heat Riser
Valve Cam Lobes	Accelerator Pump	ESC Vacuum Valves		FI Throttle Valve
Valve Guides	Ignition Wires	ESC Temp Switch		FI Idle Adjustment
Piston Rings	Metering Jets	Dist Vac Decel Valve		EGR Vacuum Amplifier

- The most emission-critical components for NO_x are typically EGR system components and components which affect vacuum advance of timing.

- The most emission-critical components for smoke from diesel engines are typically mechanical and fuel injection components.

- Except for ignition system components, most faulty emission-critical components cannot be readily detected by the vehicle owner or even by an automotive mechanic unless specific diagnostic procedures are used which are not now routinely performed during scheduled maintenance. (See Table 1-3 for characteristic symptoms of component failure.)

A series of tests were recommended on 25 components to develop or refine data on emissions increases and symptoms of failure. These components are summarized in Table 1-4.

1.2 STATEMENT OF THE PROBLEM

The Clean Air Act (Section 207c) requires that all new vehicles and vehicle engines are to be warranteed by the vehicle or engine manufacturer to be designed, built, and equipped so as to conform with applicable emission standards for 50,000 miles providing that they are maintained, serviced, and operated in accordance with written instructions provided to the vehicle owner. Classes (i.e., engine families of vehicles or vehicle engines) which are found to violate the applicable emissions standard during the 50,000-mile warranty period are subject to recall and corrective repair at the

Table 1-3. SYMPTOMS OF COMPONENT FAILURE

DEFECTIVE COMPONENTS	CRITICAL POLLUTANT				SYMPTOM OF FAILURE				
	HC	CO	NO_x	Smoke	Hard Starting	Drive-ability	Rough Idle	Fuel Economy	Back-Firing
Carburetion System									
Choke Components	x	x			x	x		x	
Metering Rods		x				x		x	
Float and Valve		x			x	x	x	x	
Power Valve	x	x			x	x		x	
Electric Assist Choke		x							
Idle Adjustment	x	x					x	x	
Vacuum Break Valve		x					x		
Ignition System									
Plugs/Wires	x	x			x	x	x	x	
Cap/Rotor	x				x	x	x		
Electronic Triggers	x				x	x	x		
Timing Adjustment			x			x		x	
Advance Mechanisms		x				x		x	
Air Induction System									
TAC Components	x				x		x		
Air Cleaner		x						x	
Vacuum Hose Leaks	x					x	x		
Turbocharger				x		x		x	

Table 1-3. SYMPTOMS OF COMPONENT FAILURE (Continued)

DEFECTIVE COMPONENTS	CRITICAL POLLUTANT				SYMPTOM OF FAILURE				
	HC	CO	NO_x	Smoke	Hard Starting	Drive-ability	Rough Idle	Fuel Economy	Back-Firing
Fuel Injection System									
EFI Trigger Switch			x		x	x	x	x	x
EFI Starting Valves		x				x		x	x
Injection Valves				x	x	x	x	x	
Pressure Reg/Sensors				x		x		x	
Mechanical System									
Valve Components	x	x		x		x	x	x	
Rings				x		x	x	x	
Gaskets				x		x	x	x	
Emission Control System									
Catalyst	x	x							
PCV Components	x	x					x		
EGR Components			x				x		
EVAP Components	x						x		
AI Components	x	x					x		x
Heat Riser	x	x			x	x	x		
TCS/SCS Components			x						
Spark Delay Valves			x						
Thermal Vac Switches			x						

Table 1-4. COMPONENTS RECOMMENDED FOR TESTING

COMPONENT	DEFECT	VARIABLE RANGE
Carburetion System		
1. Choke	Improper Adjustment	Normal Opening - Delayed Opening
2. Float and Valve	Improper Float Level	1/8" Low - 1/8" High
3. Power Valve	Stuck Open or Ruptured Diaphragm	Operational - Failed
4. Idle Adjustment	Improper Mixture	1/2 Turn In - 1/2 Turn Out
5. Metering Rod	Improper Adjustment	1/8" Low - 1/8" High
6. Vacuum Break Valve	Ruptured Diaphragm or Loose Vacuum Hose	Operational - Failed
Ignition System		
1. Spark Plugs	Electrode Deterioration	Wide Gap - Fouled
2. Wires	Cable Deterioration	Open - Grounded
3. Cap	Terminal Corrosion or	New - Old
4. Rotor	Terminal Erosion	New - Old
5. Vacuum Advance	Ruptured Diaphragm or Loose Vacuum Hose	Operational - Failed
6. EI Mag Trigger	Deteriorated	New - Old
7. Basic Timing	Improper Adjustment	SPEC -10^{0} - SPEC $+10^{0}$
Air Induction System		
1. Thermal Air Inlet	Ruptured Diaphragm or Loose Vacuum Hose	Operational - Failed (Open)
Mechanical System		
1. Valve Adjustment	Improper Lash	Specification - 1/16" Excess
2. Exhaust Valve	Burned or Eroded	New - Old
Emission Control System		
1. Heat Riser	Stuck	Operational - Failed (Open)
2. Catalyst	Melted (Overheated)	Operational - Failed
3. Air Injection System	Hose or Pump	Operational - Failed
4. PCV Valve	Clogged	Operational - Failed (Closed)
5. Spark Delay Valve	Stuck	Operational - Failed (Open)
6. EGR Valve	Stuck	Operational - Failed (Closed)
7. Backpressure Sensor	Clogged	Operational - Failed
8. EGR Thermal Valve	Stuck	Operational - Failed (Closed)
9. Thermal Vac Valve	Stuck	Operational - Failed (Open)

manufacturer's cost in accordance with Section 207e of the Clean Air Act. As a result of the warranty provisions of the Clean Air Act, manufacturers have issued specific maintenance schedules covering those adjustments and component replacements which the manufacturers have found to be important in maintaining compliance with the emission standards for 50,000 miles.

However, surveillance test programs have shown that a relatively high proportion of in-use vehicles fail to comply with prescribed emission standards. These failures are generally related to malfunctions of specific components of the engine or emission control systems which may be defective, tampered with, or improperly adjusted. A key step in correcting these emission failures is to identify those components which are malfunctioning, how these malfunctions affect emissions, and how they can be detected. With this information, the EPA can then take the necessary action to ensure compliance through recall programs and improved maintenance procedures.

1.3 STUDY OBJECTIVES

The objective of this study was to assess the relative importance of engine and emission control components in causing excessive emissions in the in-service vehicle population. The importance of each component was measured by a criticality index based on factors representing:

- Impact on emissions of a single vehicle with a defective component
- Probability of defect occurrence
- Duration of defect occurrence
- Relative usage of each component.

1.4 STUDY SCOPE

This study was conducted in two phases with separate reports issued for each phase. Phase I consisted of an assessment of the criticality of original factory-installed (OEM) equipment. Phase II consisted of an assessment of the criticality of after-market equipment including both high performance equipment and OEM equivalent replacement components. Both Phases of this study were accomplished without vehicle testing but were supported by a literature search and engineering analysis.

The emission-criticality of parts, components and systems was determined separately for the following regulated emissions: hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x) and smoke opacity. The criticality rankings were established for 1972 and subsequent model-year engines and vehicles. All engines subject to regulation were within the nominal scope of the study; however, as a practical matter, diesel engines and heavy-duty gasoline engines were not included in the criticality ranking of HC, CO, and NO_x because of their relatively low occurrence in the population. For the same reason, manufacturers of light-duty vehicles whose total sales in the U.S. were less than 1 percent of the applicable model-year vehicle production were excluded. The emission-criticality of components for smoke were based on the most popular heavy-duty diesel engines.

Because of the very large number of individual components used by engine and vehicle manufacturers, it was impossible to assign individual parameters to each component. Rather, components were grouped into classes whose members had similar function and configuration. Each class or category of components was then assigned parameter values which were applicable to all individual components within each category.

1.5 STUDY PLAN

Figure 1-1 illustrates the sequence and interrelationship of the tasks of each phase of this study. The initial effort was directed towards the literature search and acquisition of pertinent data. Simultaneously, the criticality index model was formulated, coded, and checked out. Subsequent Phase I activity included the following tasks:

- Identify emissions-related systems and components.
- Determine characteristic failure mode of each component.
- Determine effect on emissions of each defect.
- Determine probability of defect occurring and probability of defect being corrected before end of component design life.
- Determine relative usage (sales volume) of each OEM component.
- Use the factors defined above to calculate a criticality index for each OEM component for each pollutant.
- Rank the components by criticality index.
- Describe symptoms of failure and appropriate diagnostic techniques for the 25 most critical components for each pollutant.
- Recommend a series of tests for 25 of the most critical OEM components to provide supportive data not available in the literature.

The above analyses, findings, conclusions and recommendations formed the basis of this report on the criticality of original equipment.

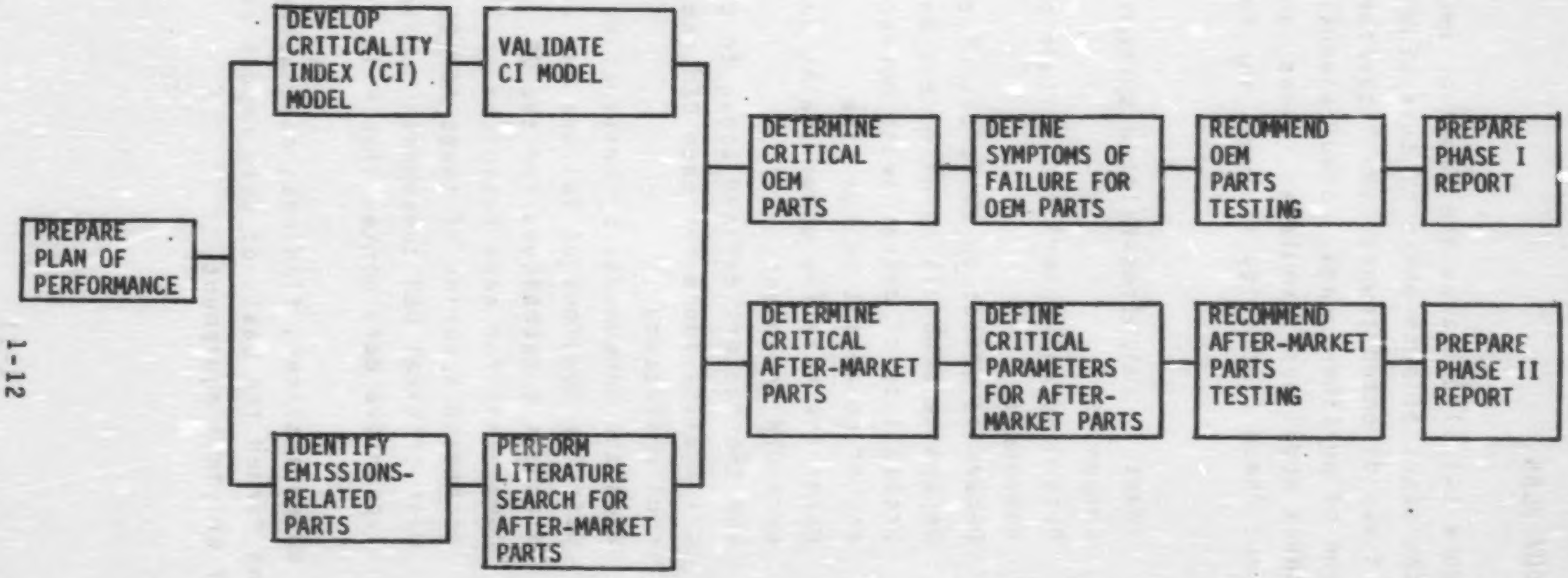

PREPARE PLAN OF PERFORMANCE
DEVELOP CRITICALITY INDEX (CI) MODEL
VALIDATE CI MODEL
IDENTIFY EMISSIONS-RELATED PARTS
PERFORM LITERATURE SEARCH FOR AFTER-MARKET PARTS
DETERMINE CRITICAL OEM PARTS
DEFINE SYMPTOMS OF FAILURE FOR OEM PARTS
RECOMMEND OEM PARTS TESTING
PREPARE PHASE I REPORT
DETERMINE CRITICAL AFTER-MARKET PARTS
DEFINE CRITICAL PARAMETERS FOR AFTER-MARKET PARTS
RECOMMEND AFTER-MARKET PARTS TESTING
PREPARE PHASE II REPORT

Figure 1-1. STUDY APPROACH

Phase II activity includes the following tasks relative to after-market components, parts, and systems:

- Redefine the values of the criticality index input parameters for after-market components.
- Execute the criticality model to select the most emission-critical after-market components for each pollutant.
- Determine the critical parameters (specifications or design characteristics) of each of the five most critical after-market components for each pollutant.
- Recommend a series of tests for 25 of the most critical after-market components.

The analysis of after-market parts is documented in a separate report.

Section 2

LITERATURE SEARCH

An extensive search was conducted during the study to identify all potential sources of information. The literature search was intended to obtain information for each component which would support the following parameters of the criticality index.

- Typical failure or defect modes.
- Probability and duration of failure.
- Consequence of the failure on emissions and performance.
- Sales volume of vehicles, engines, and components.

The literature search was performed by a professional search organization and included the following data bases:

- National Technical Information Service (NTIS)
- Chemical Abstracts
- Engineering Index
- Pollution Abstracts

The formal literature search was directed chiefly toward evaluating the effect of component defects on emissions. The literature search was conducted using the key words shown in Table 2-1. Unfortunately, the search was extremely broad, resulting in approximately 600 citations of potentially applicable reports. Review of the cited titles and descriptors reduced to approximately 100 the number of reports which appeared to deserve detailed review.

Table 2-1. KEY WORDS USED FOR LITERATURE SEARCH

Automobile(s)
Automotive
Carbon Monoxide
Carburetion
Carburetor(s)
Catalyst(s)
Component(s)
Diesel
Durability
Electrical
Emission(s)
Engine(s)
Exhaust
Expected Life
Fuel Economy
Hydrocarbon(s)
Ignition
Internal Combustion
Maintainability
Mileage
Mobile Source(s)
Nitroic Oxide
Oxide(s) of Nitrogen
Parts
Reactor
Smoke
Spark Ignition
Vehicle

In addition to the formalized literature search, extensive research was performed to define the type, quality, and availability of data on performance and production of engines, components, and systems. This research involved discussions with industry and government representatives to evaluate the applicability and accessibility of unpublished data. This evaluation indicated that, in general, data of the detail required by this study did not exist except for a few specific components.

The discussion of the literature search is divided into the following subject areas:

- Component usage.
- Effect of component failure on emissions.

- Probability and duration of component failure.
- Sales volume.

2.1 COMPONENT USAGE

In order to identify emissions-related components, it was necessary to determine which components and systems were used on 1972 and later vehicles. The EPA has adopted the concept of engine families for engines or vehicles which have similar engine/carburetion/emissions control system configuration. However, the engine family designations did not necessarily reflect differences in body style, transmission type and accessory equipment even though these factors can result in different component usage. It was desirable to obtain assembly parts lists by make/model/power train. Unfortunately, this information was not available from either the vehicle manufacturers or the EPA. Therefore, an alternate source was sought out.

The source eventually selected to define component usage was the Emission Control Service Manuals (Ref. 27) published by Mitchell Manuals, Inc., San Diego, California. The supplements for the model-years 1972 through 1975 were obtained and used to define each distinctive engine family according to the major emission control equipment configuration. The manuals distinguished families by engine, carburetor, transmission and, in some cases, accessory equipment. Differences in system configurations for California and Federal vehicles were identified. Vacuum and electrical diagrams were also presented permitting analysis of the influence of defects in certain components on the performance of related components.

2.2 EFFECT OF COMPONENT FAILURE ON EMISSIONS

Twenty-seven papers were reviewed which described the influence of engine and control system design on emissions. These papers generally were based on prototype tests using nonstandard systems (CFR engines) or operating conditions (steady states). Unfortunately, none of these papers provided pertinent data on the probability or effect on emissions of malfunctions in the engine or system being evaluated. Several of these papers also discussed systems which have not been produced for sale. Table 2-2 summarizes the design and development papers which were reviewed but which did not provide useful data or information.

Several papers (Ref. 19, 22, 37, 38, 40, 46, 48, 58, and 60) and books (Ref. 2 and 3) were used to help define the operating principles and design characteristics of engine or emission control systems. In general, these documents did not provide data on the probability of failure or the effect of defects on FTP emissions. They did, however, provide a basis for establishing probable modes of failure.

Several papers (Ref. 35, 47, 72, 73, and 82) reported durability test results on production prototype vehicles. These papers, generally, did not describe specific defects and their effect on emission levels. The papers, however, did give some insight into the probability of failures and some typical system problems. Presumably, characteristic failures detected during durability testing were corrected prior to production.

Weaver, et al (Ref. 35), reported data on a fleet of 450 prototype catalyst vehicles. In general, they found that maintenance performed in accordance with the manufacturer's recommended schedule enabled the vehicles to maintain emission levels within 1975 statuatory standards for the 50,000-mile certification period. Furthermore, the maintenance actions did not affect HC emissions, decreased CO

Table 2-2. ENGINE DEVELOPMENT LITERATURE NOT APPLICABLE TO AUTOMOTIVE PARTS STUDY

REFERENCE NO.	TITLE	SOURCE
1	Extension of the Lean Misfire Limit and Reduction of Exhaust Emissions of an SI Engine by Modification of the Ignition and Intake Systems.	SAE 740105
4	Questor Reverter Emission Control System Total Vehicle Concept.	SAE 730227
6	Control of Refueling Emissions with an Activated Carbon Canister on the Vehicle.	SAE 751181
8	EFI Prechamber Torch Ignition of Lean Mixtures.	SAE 750351
9	Emissions Study of a Single-Cylinder Diesel	SAE 740123
10	Factors Affecting Dual Catalyst System Performance	SAE 740252
11	A Study of Ignition System Effects on Power, Emissions, Lean Misfire Limit, and EGR Tolerance of a Single-Cylinder Engine - Multiple Spark Versus Conventional Single Spark Ignition.	SAE 740188
18	Efficient and Clean Diesel Combustion.	SAE 750787
21	Trade-Offs between Engine Emission Control Variables, Fuel Economy, and Octane.	SAE SP-395
23	Emissions Control of a Stationary Two-Stroke Spark-Gas Engine by Modification of Operating Conditions.	Inst. of Gas Technol, Chicago 6/5-7/72

Table 2-2. ENGINE DEVELOPMENT LITERATURE NOT APPLICABLE TO AUTOMOTIVE PARTS STUDY (Continued)

REFERENCE NO.	TITLE	SOURCE
25	Closed Loop Carburetor Emission Control System	SAE 750371
30	Teledyne Continental Motors Red Seal Engines First CPCS Application.	SAE 750017
31	New Concept in Automotive Ignition.	Automot. Eng.,v 84, n3, 3/75
32	Divided Combustion Chamber Gasoline Engines - A Review for Emission and Efficiency.	APCA 73-74 6/24-28/73
34	Exhaust Purifiers for Compression Ignition Engines.	Platinum Met Rev, v 19 n1, 1/75
36	Lean Combustion and the Misfire Limit in Spark Ignition Engines.	SAE 741055
39	Electronic Closed Loop Controls for the Automobile.	SAE 740014
41	Physical and Chemical Characteristics of Particulates in Spark Ignition Engine Exhaust.	Environ. Sci. Technol, v 8, n4, 4/75
44	Initial Performance of Supported NO_x Reduction Catalysts in a Dual-Catalyst System.	SAE 740251
45	Texaco Controlled Combustion System Multifuel, Efficient, Clean and Practical	Combust. Sci. Technol, v 8, n
50	Mechanisms of Polynuclear Aromatic Hydrocarbon Emissions from Automotive Engines.	SAE 730835

Table 2-2. ENGINE DEVELOPMENT LITERATURE NOT APPLICABLE TO AUTOMOTIVE-PARTS STUDY (Continued)

REFERENCE NO.	TITLE	SOURCE
55	Simulated Road Test Evaluation of the Effect of Gasoline Additives on Exhaust Gas Emissions.	SAE 720942
61	Control of Exhaust Pollution through a Mixture Optimizer.	SAE 720254
62	Closed Loop Control of Internal Combustion Engine Exhaust Emissions.	PB-239 850/1ST DOT-OS-30 111 2/74
77	Emissions Control Technology of Heavy Duty Vehicle Engines.	PB-236 899/1ST EPA-68-01-0472 12/73
76	Experiments with a Catalytic Cleaner for Car Engine Exhaust Gases.	N75-12455/2ST FOA-1-C-1492-H3 12/72
88	An Evaluation of the Emissions Characteristics of the Exxon Well Mixed Thermal Reactor.	PB-220 034/3 APTD-1387, 72-3

emissions and increased NO_x emissions. Unfortunately, the report did not relate specific maintenance actions or defects to changes in emissions of individual vehicles.

The Weaver study also indicated that overtemperature operation caused the greatest number of catalyst failures. However, partially melted catalysts were found to have residual activity although the 1975 HC and CO statuatory standards were exceeded slightly. Examination of the vehicles with melted catalysts showed that 14 catalysts were damaged by intermittent or total ignition loss occurring within 10,000 miles. The ignition failure was traced to defective breaker points (five cases), primary coil wires (seven cases), or ignition coil failure (two cases). In addition, two catalysts were damaged by intermittent ignition misfire occurring at greater than 10,000 miles. One each of these failures was attributed to a loose primary coil wire and a faulty coil. There were no cases of catalyst melting caused by rich carburetion or other emission control system defects. Although all catalyst failures were caused by ignition failures, the incidence of ignition failure was small relative to the fleet size (3.5 percent) which is characteristic of the in-service noncatalyst vehicle population.

Miles, et al (Ref. 47), described a durability program of approximately 250 catalyst vehicles. Several alternative design configurations and prototype components were evaluated to establish performance data. In general, catalyst systems performed within their design emission standard for the 50,000-mile durability test. Specific data on the effect of component failure were not presented, although some vehicles did exceed one or more of the standards and some catalysts failed. Difficulty was reported with prototype high energy ignition components which resulted in misfire due partly to plug fouling. Ignition misfire was believed to have caused the catalyst failures. However, converter failures occurred when at least two cylinders were misfiring. More rapid deterioration of HC than CO emissions generally occurred, with NOx emissions showing little deterioration.

A review of catalyst technology was prepared by the National Academy of Sciences (Ref. 15, 69, 72, 73, and 74). Deactivation of catalysts was determined to be due to thermal cycling and excessive temperatures (Ref. 72). The catalytic media was sintered and agglomerated resulting in increased void (pore) size and decreased surface area. Severe thermal stress lead to structural deformation (melting and collapse).

The following specific defects leading to catalyst failure were identified from surveys of catalyst development and durability testing (Ref. 72, 73, and 82):

- Severe dieseling after ignition shut-off.
- Running out of fuel at high speed.
- Failure of coasting protection (deceleration controls).
- Misfire caused by ignition failure.
- Complete ignition failure at moderate to high speed.
- Stuck choke.
- Fuel which causes plug fouling.

The frequency and duration of failure and the effectiveness of protective devices (air injection dump) determined the degree to which the catalyst was degraded or destroyed. If the catalyst were to become essentially deactivated and all other defects were corrected, the average emission level from catalyst-equipped vehicles was estimated at 2.5 gm/mi HC, 18.0 gm/mi CO, and 5.0 gm/mi NO_x.

A summary NAS report (Ref. 70) presented a compilation of emission-critical components which has been abstracted and is shown in Table 2-3. These data represented the opinion of the NAS committee based on data available prior to 1973.

Matsumoto, et al (Ref. 7), described an analysis of catalyst reliability based on empirical data. The analysis was performed to rank various component defects in order of their criticality in causing catalyst failure. Catalyst failure was found to be critically-related to high temperature. Factors causing high catalyst temperature included hydrocarbon concentration (misfire), exhaust gas temperature at the inlet to the catalyst, and flow rate of the exhaust gas. Criticality of each defect was determined by the product of a damage intensity factor and probability of repair factor. The criticality ranking of the components was as follows:

- Two cylinders misfiring.
- One cylinder continuously misfiring.
- One cylinder intermittently misfiring.
- One cylinder occasionally misfiring.
- Choke valve stuck.
- Fuel restriction (lean operation).
- Plugged air bleed.
- Main jet fell out.
- Carburetor flooding.
- Primary jet fell out.

A study (Ref. 17) for the California Air Resources Board (CARB) investigated the sensitivity of FTP emissions to various changes in test conditions and engine adjustments. Tests were performed on catalyst- and noncatalyst-equipped vehicles. Pertinent parameters investigated included idle speed, basic timing, and idle mixture. Unfortunately, the emissions were tested using the hot start 1972 FTP. Therefore, results using cold start FTP tests may be somewhat different. The results are summarized in Table 2-4 in

Table 2-3. EFFECT ON EMISSIONS OF VARIOUS COMPONENTS[1]

NO.	ITEM	HC	CO	NO_x	MEAN TIME TO FAILURE, YEARS	SERVICE INTERVAL, YEARS
Major Control Equipment						
1*	3-way catalyst (HC, CO, NO_x)	H	H	H	2	1
2*	Reduction catalyst (NO_x)			H	2	1
3*	Oxidation catalyst (HC, CO)	H	H		2	1
4*	Exhaust manifold reactor	M	M		10	5
5	Exhaust gas recirculation valve			H	5	1
6	Air injection pump	M	M	L	5	1
These Can Cause A Catalyst Failure						
7*	Catalyst bypass	H	H		5	1
8*	Catalyst thermocouple	H	H		2	1
9*	Exhaust manifold reactor bypass	M	M		5	1
10*	Exhaust air diverter valve	M	M	H	8	1
11*	Oxygen sensor for 3-way catalyst	M	M	M	2	1
12*	Electronic feedback control	M	M	M	8	1
13*	Electronic fuel injection	M	M	M	8	1
14*	Fast acting choke	H	H	L	5	1
15	Float valve	M	H	L	5	5
16	Power jet	L	L	L	10	5
17	Fuel pump	L	L	L	5	5
18	Spark plugs	H		M	2	1
19	Plug wires	H		M	3	1
20	Electronic ignition	L	L		10	1
21	Exhaust valve leaks	H		M	10	2

[1] Table 12 from Reference 70.

*Components not in production prior to 1973.

Table 2-3. EFFECT ON EMISSIONS OF VARIOUS COMPONENTS[1] (Continued)

NO.	ITEM	HC	CO	NO_x	MEAN TIME TO FAILURE, YEARS	SERVICE INTERVAL, YEARS
These Can Have A Major Effect on Emissions						
22	Idle mixture screw	H	H	L	10	1
23	Idle speed screw	L	L		10	1
24	Fast idle speed screw	L	L		10	1
25	Heat riser valve	M	M		8	1
26	Air filter	L	M		2	1
27	PCV valve	M	M		3	1
28	PCV fittings and hoses	L	L		5	1
29	Distributor cap	M			5	1
30	Points	H			4	1
31	Coil wire	H			5	1
32	Air pump belt	H		L	5	1
33	Transmission controlled spark switch			M	5	1
These Can Have Effect on Emissions						
34	Coolant thermostat			L	5	5
35	Vacuum advance	M		M	5	2
36	Battery	L		M	3	2
37	Battery cables	L			5	2
38	Voltage regulator	L			5	5
39	Distributor rotor	M			5	1
40	Ignition condenser	M			8	1
41	Coil	H			10	1
42	Centrifugal advance	M		M	10	1

[1] Table 12 from Reference 70.

Table 2-3. EFFECT ON EMISSIONS OF VARIOUS COMPONENTS[1] (Continued)

NO.	ITEM	HC	CO	NO_x	MEAN TIME TO FAILURE, YEARS	SERVICE INTERVAL, YEARS
43	Intake manifold leaks	M	L		5	2
44	Carburetor metering rods	M	M	L	8	2
45	Carburetor internal vents	L	M	L	10	1
46	Carburetor float	M	M	L	10	10
47	Fuel filter	L	L		2	2
48	Carburetor accelerator pump	L	L		5	5
49*	Quick heat manifold	L	M		10	10
50*	PCV delay solenoid	L	L		5	2
51*	Thermistor to sense coolant	L	L		5	5
52*	Solenoid to activate EGR			M	5	1
53*	Solenoid to activate evap. CS	L			5	1
54	Activated carbon ECS	L			5	5
55	Anti dieseling solenoid valve	L			3	3
56	CAP vacuum advance valve	M			8	5
57	Air injection check valve	M			5	5
58	Air cleaner thermostat	M	M	L	5	5
59	Distributor vacuum control valve	M		M	5	5
60	Gulp valve				5	5
61	Vacuum lines				3	2

[1] Table 12 Reference 70.

*Components not in production prior to 1973.

percent change relative to a hot start 1972 FTP baseline test.

Table 2-4. EFFECT OF IDLE PARAMETERS ON HOT FTP EMISSIONS (REF. 17)

	PRE-CATALYST			CATALYST-EQUIPPED		
	HC	CO	NO_x	HC	CO	NO_x
Timing +5°	+10%	-	+15%	-	-30%	+20%
Idle CO +1%	-	+15%	-	+100%*	+100%*	-
Idle Speed -100 rpm	+10%	+10%	-	-	-25%	

*Baseline emissions approximately 1/3 of standard.

The California Air Resources Board (CARB) performed two studies (Ref. 92 and 93) of defects in catalyst-equipped vehicles. Table 2-5 summarizes these results in terms of the increase (decrease) on emissions attributable to specific component defects. The results of these studies show that misfire due to faulty plugs or wires was the most critical HC-related defect. Other critical defects included choke malfunctions, air injection failure, lean misfire caused by vacuum leaks and incorrect timing (10° retarded). The most critical CO-related defects were air injection failure, choke malfunction, retarded timing, and misfire. The most critical NO_x-related defects were clearly disabled EGR systems and advanced basic timing.

Maugh (Ref. 100) presented data, shown in Table 2-6, on defect testing of the three different 1976 Federal certification vehicles. These data and other information discussed in the paper led to the following conclusions:

- Restricted air cleaner or timing variations of ±10° did not significantly affect FTP emissions.

Table 2-5. CHANGES IN 1975 FTP EMISSIONS CAUSED BY SPECIFIC DEFECTS
(PERCENT INCREASE FROM BASELINE EMISSIONS)

DEFECT	INDUCED DEFECTS[a]				DIAGNOSED DEFECTS[b]			
	Number of Vehicles	HC	CO	NO_x	Number of Vehicles	HC	CO	NO_x
No EGR	6	33	33	65	3	0	12	65
Plugs/Wires	6	833	252	41	3	731	14	35
Vacuum Leak	6	83	73	0	1	150	-32	11
Timing (advanced)	6	17	2	35	1	-23	-47	64
Timing (retarded)	6	133	355	-12	0	-	-	-
Air Failure	0	-	-	-	6	160	365	-9
Choke Stuck	6	433	298	-12	3	60	170	-15
Carburetor Mixture	0	-	-	-	3	33	26	4
Idle Stop Solenoid	0	-	-	-	1	150	33	15
Dirty Air Filter	6	50	62	0	0	-	-	-

[a] Defects induced in low mileage catalyst vehicles (Ref. 92).

[b] Defects diagnosed in low mileage catalyst vehicles which failed an idle HC screening standard of 200 ppm Hexane (Ref. 93).

Table 2-6. EFFECT OF COMPONENT DEFECTS ON 1975 FTP EMISSIONS
(EXHIBIT V OF REF. 101)

	2.3L 4-CYLINDER			351 CID 8-CYLINDER			460 CID 8-CYLINDER		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
Baseline	0.51	2.31	1.76	0.62	4.97	1.24	0.51	3.04	1.46
Air Cleaner Restricted 75%	0.47	2.14	2.18	0.60	5.06	1.08	0.40	1.70	1.41
Timing +10^0	0.60	3.52	3.12	0.63	3.75	1.65	0.51	2.13	1.81
Timing -10^0	0.49	2.34	1.19	0.55	5.02	0.93	0.32	3.22	1.23
EGR Line Off	0.43	1.56	6.44	0.44	2.69	4.25	0.33	1.55	5.60
Thermactor Disconnected	0.68	11.10	1.32	2.23	69.30	0.93	2.46	66.10	1.24
Choke Restricted 50% Travel	0.50	3.95	1.45	0.57	6.84	0.85	17.80	322.00	0.35
Spark Plug Wire Grounded	10.20	7.57	2.84	4.11	4.65	1.69	2.61	8.57	2.55

- Disconnected air injection caused significant increases in HC and CO emissions but reduced NO_x emissions.

- A stuck choke increased HC and CO emissions on large engines but not necessarily on small engines. NO_x emissions were reduced, significantly on large engines.

- Total misfire caused significantly higher HC emissions particularly on small engines. CO and NO_x emissions also increased although not as much as HC emissions.

Two EPA studies investigated tampering and maladjustments of 1973-1975 model-year vehicles. Timing maladjustments of up to $\pm 5^{\circ}$ alone resulted in 10 percent to 20 percent increases in FTP emissions of HC and CO from 1975 model-year vehicles. Emissions of NO_x were increased 20 percent by a 5° advance in timing and reduced 20 percent by retarding timing 5° (Ref. 98). Several 1973-1974 model-year vehicles were sent to commercial garages to have their fuel economy improved. Although most adjustments did not improve fuel economy, emissions of all three pollutants were increased with NO_x and CO receiving the greatest increase (Ref. 97). These data indicated that intentional maladjustment or defeat of emission controls resulted in significant emissions increases without actual component failures.

The EPA/CRC CAPE-13-68 study (Ref. 16) included an analysis of several common adjustment and component defects in pre-1972 model-year vehicles. Variables studied in the controlled experiment included timing, idle speed, idle mixture, air cleaner restriction, PCV restriction, and NO_x TCS defeat. Emissions were reported in grams per mile and were measured using hot start 1972 FTP tests. The data in Table 2-7 was reported for 1971 NO_x controlled vehicles.

Table 2-7. EFFECT OF COMPONENT DEFECTS ON HOT FTP EMISSIONS (Ref. 16)

	HC	CO	NO_x
Timing (gm/mi/degree advance)	0.08	-0.90	0.15
Idle Speed (gm/mi/100 rpm)	-0.15	2.80	0.07
Idle Mixture (gm/mi/% CO)	-0.07	6.53	-0.03
½ Blocked Air Cleaner (gm/mi)	0.18	12.42	-0.48
PCV Blocked (gm/mi)	0.36	18.03	-0.33
TCS Defeat (gm/mi)	0.55	-6.30	0.99

All changes were relatively small with respect to the effective emission standards of 1971 model-year vehicles. Direct comparison to 1972 and later model-year vehicles is difficult, however, because these data were based on hot start tests and did not reflect changes in engine and emission control system design applicable to recent model years.

Panzer (Ref. 12 and 96) discussed the idle emission test program performed by Exxon. The first paper included a survey of 23 previous papers relating component defects to qualitative steady-state emissions (Table 2-8). No quantitative data based on FTP emissions were presented, however, substantial HC and CO emission reductions were achieved by performing adjustments and repairs to correct idle mixture, engine speed, timing, PCV system restriction, ignition and carburetor malfunctions, vacuum leaks and valve leaks.

Table 2-8. EFFECT OF ENGINE VARIABLES ON STEADY STATE EMISSIONS FROM PRE-1973 VEHICLES (TABLES 3 AND 4, REF. 12)

VARIABLE	IDLE		LOADED	
	CO	HC	CO	HC
Increased A/F	Decrease	Decrease to Stoichiometric	Decrease	Decrease to Stoichiometric
Increased RPM	Decrease	-	None	Decrease
Restricted PVC	Increase	-	Increase	Increase
Restricted Air Cleaner	Increase	-	Increase	Increase
Stuck Choke	Increase	-	Increase	Increase
Carburetor Malfunction	Increase	-	Large Increase	Increase
Ignition Malfunction	-	Increase	-	Increase
Retarded Timing	-	Increase	None	Decrease
Stuck Heat Riser	Increase	-	-	-
Excessive Fuel Pressure	Increase	-	-	-
Exhaust Valve Leaks	-	Increase	-	Increase
Vacuum Leaks	Increase	Increase	-	Increase
Decel Device Failure	-	-	-	Increase
Spark Advance Failure	-	-	-	Increase
Air Pump	-	-	Increase	Increase
Air Inlet Temp. Increase	-	Slight Increase	-	-

Several reports (Ref. 16, 33, 42, 43, 49, 51, 54, 60, 74, 78, 84, 94, 95, and 99) discussed various Inspection and Maintenance (I/M) studies. These reports indicated that I/M was effective in reducing emissions of HC and CO. Unfortunately, only a few of these studies were performed on catalyst-equipped vehicles and none associated emissions increases or decreases to individual component defects.

Springer (Ref. 63) reported extensively on smoke emissions from diesels. Control of smoke emissions were primarily due to modifications to injector pumps, injector tips, spray pattern, duration and timing. In some applications, introduction or modification of turbochargers reduced smoke. Control requirements for NO_x, however, tend to increase smoke emissions due to premature flame quenching in the cooler combustion gases. Control of smoke from in-use vehicles, however, is more related to engine power derating, retrofit components, or modified driver operating procedures. Except in severe conditions, normal maintenance generally did not make significant changes in smoke emissions, providing that basic adjustments of the fuel injection system were made to manufacturer's specification.

2.3 PROBABILITY AND DURATION OF COMPONENT FAILURE

Several of the references describing emissions characteristics of defective components also provided data on failure rates of components or systems. No data, however, was obtained regarding probable duration of failure, although most sources implied a strong relationship between performance degradation and corrective repair. However, in practice, driver sensitivity to, and tolerance of, performance degradation varies and depends, in part, on the nature and severity of degraded performance, vehicle age, and the imagined or real cost of repair.

Inspection and Maintenance (I/M) studies provided some data on the incidence of system failures in the vehicle population. Unfortunately, the failure criteria and the observed failure rates varied considerably. Most studies related failure criteria to modal emission characteristics (Ref. 33, 42, 43, 49, 60, 79, 84, 94, 95, and 99). These studies identified high incidences of incorrect basic idle adjustments. Other studies which involved parameter inspection or performance criteria generally detected more component failures than the emission inspection studies (Ref. 16, 78, 101, and 102).

The observed failure rates, regardless of the inspection criteria and methodology, reflect an average of continually occurring component failures and repairs. Therefore, using inspection data to define component failures, may not truly reflect the probability of an individual component failing. It only represents the probability of finding defects at any one time in a vehicle population. The true failure rate is, therefore, likely to be higher than detected for components which are likely to be repaired. The failure rate is likely to be about the same as indicated for components which are not likely to fail or be repaired.

Panzer (Ref. 12) summarized several prior studies in addition to data from the Exxon Research idle fleet. This data is presented in Table 2-9.

Catalyst durability studies provided some data on component failure as described in Section 2.2. The NAS summary document (Ref. 70) provided preliminary data on mean time to failure or suggested maintenance intervals for some selected components. These data are shown in Table 2-10.

Catalyst durability studies also showed that ignition defects severe enough to cause catalyst malfunction occurred on only 3 to 5 percent of the vehicles. Other component failures were not described because they generally did not occur or they did not adversely affect catalyst life.

Table 2-9. INCIDENCE OF MALFUNCTIONS (ABSTRACTED FROM TABLES 7 AND 8 OF REF. 12)

DESCRIPTION	ALL VEHICLES		REJECTED VEHICLES	
	Survey (Percent)	Exxon (Percent)	Survey (Percent)	Exxon (Percent)
Ignition	4 - 78	12 - 18	12 - 30	51
Mixture	60	26 - 40	-	28
Engine RPM	70	38 - 55	-	38
Carburetor	24	4 - 10	15 - 20	17
Choke	-	1 - 4	-	13
Timing	76	4 - 27	-	10
PCV Valve	-	1 - 4	-	7
Air Filter	-	1 - 5	-	6
Vacuum Leak	-	1 - 2	-	6
Heat Riser	9	11 - 3	-	0
Vacuum Advance	-	1 - 4	-	1
Air Pump	11	-	-	-

Table 2-10. ESTIMATED DURABILITY OF AUTOMOITVE PARTS
(TABLE 13 OF REF. 70)

SYSTEM PARAMETERS	MEAN TIME-TO FAILURE (MI)		SERVICE INTERVAL (MI)
	Scott Labs.	American Motors	Chrysler
Carburetion			
A/F at idle	15,000	25,000	12,000
A/F at main jet	30,000	--	12,000
A/F power jet	--	--	12,000
Choke	25,000	25,000	6 months
Heat Riser valve	25,000	5,000	6 months
Altitude compensation	--	--	--
Leaks intake manifold	50,000	50,000	--
Leaks vacuum line	35,000	50,000	Infrequent
Air cleaner - plugged	20,000	15,000	12,000
Ignition			
Misfire--plugs	20,000	15-30,000	18,000
Misfire--wiring	25,000	50,000	Infrequent
Misfire--cap and rotor	30,000	50,000	Infrequent
Basic timing	15,000	15,000	12,000
Automatic spark advance	25,000	100,000	12,000
Devices			
PCV system	30,000	15,000	12,000
EGR system	--	12-50,000	12,000
Air pump system	40,000	100,000	12,000
Oxidation catalyst	25,000	12,000	--
Reduction catalyst	25,000	--	--
Evaporative control system	70,000	50,000	12,000
Other			
Idle speed	15,000	15,000	12,000
Burned exhaust valve	90,000	100,000	Infrequent
Low compression	60,000	100,000	Infrequent

A consultant report to the NAS (Ref. 73) described some probable maintainability and reliability data for 1975-1976 configuration vehicles:

- EGR maintenance should be reduced by lead-free fuel because particulate (deposits) emissions are reduced.
- Spark plug life should be increased by lead-free fuel and high energy ignition system.
- Ignition wire life should be increased by improved insulation and conductor materials.
- Heat riser service interval should be extended four to five times due to lead-free fuel.
- Electronic ignition should minimize changes in spark timing and firing due to point failure, thereby reducing misfire.
- Vacuum line, vacuum motor, vacuum diaphragm, and exhaust pressure diaphragm malfunction should be low (fraction of 1 percent in the vehicle population).

The California Bureau of Automotive Repair reported the failure incidences at the Vehicle Inspection Facilities in Riverside (Ref. 94). These data are reported in Table 2-11 and include about 900 failed vehicles. The decision on whether repairs were required were based on an engineering evaluation of ignition and emission data before and after maintenance. In general, a low incidence of ignition malfunctions were found with most failures due to idle adjustments and off idle carburetion problems.

Table 2-11. REPAIRS PERFORMED DURING CALIFORNIA VEHICLE EMISSION INSPECTION PROGRAM (ABSTRACTED FROM TABLES 13 THROUGH 21, Ref. 94)

DESCRIPTION	PERCENT OF FAILED VEHICLES RECEIVING REPAIR	PERCENT OF FAILED VEHICLES REQUIRING REPAIR
Idle Adjustment	100	82
PCV Filter Replacement	2	2
Choke Adjustment Repair	3	3
Carburetor Overhaul (Kit)	16	8
Carburetor Replacement (New or Rebuilt)	4	1
Air Filter Replacement	13	3
Spark Plug Replacement	12	3
Point Replacement	12	2
Condenser Replacement	10	2
Rotor Replacement	4	1
Ignition Wire Replacement	5	3
Heat Riser Repair	1	1
Heated Air Inlet Repair	<1	<1
Air Injection System Repair	<1	<1
Compression Check for Engine Defects	1	1
Other Repairs (Mechanical, Miscellaneous, Ignition, Vacuum System, etc.)	4	1

The CARB reported on the incidence of failures found in low mileage catalyst vehicles which failed an idle HC screening standard (Ref. 93). These data are reported in Table 2-12. The determination of whether a defect existed or not was based on a diagnosis performed by CARB technicians.

Table 2-12. INCIDENCE OF DEFECTS IN LOW MILEAGE CATALYST VEHICLES (REF. 93)

DEFECTS	PERCENT OF FAILED VEHICLES	PERCENT OF ALL VEHICLES
Ignition Misfire	12	0.8
Mixture	15	1.0
Engine Speed	9	0.6
Carburetor	3	0.2
Choke	9	0.6
Timing	15	1.0
PCV Valve	3	0.2
Air Filter	30	2.0
Vacuum Leak	12	0.8
Heat Riser	0	0
Vacuum Advance	3	0.2
Air Pump/Hose	15	1.0
EGR Failed/Defeated	15	1.0
Thermal Air Cleaner	6	0.4
Catalyst	3	0.2
Other Defects	18	1.2

2.4 SALES VOLUME

Data on the sales volume of emissions-related components was not available in a form useful to this study. Therefore, the component usage information described in Section 2.1 was combined with data on engine family sales volume and recommended replacements of each component to estimate the probable component sales volume.

The scheduled replacement intervals were obtained from the manufacturer's recommended maintenance schedules. In general, the same maintenance schedules applied to all engines produced or sold by each vehicle manufacturer.

Sales information by engine family was obtained from production data submitted to the EPA by Ford, General Motors, Chrysler, and American Motors Corporation for the 1975 and part of the 1976 model-year. Data was requested directly from the major manufacturers, but the requested data was not submitted to Olson. Supplemental data on production volume of vehicles by make, model, and model-year were obtained from the Automotive News Yearbooks for 1974 and 1976 (Ref. 26) and from the Automotive Industries Statistical Issues for 1975 and 1976 (Ref. 103).

Section 3

EMISSIONS-RELATED COMPONENTS

This section describes the emissions-related systems and their components. Functions, typical applications and characteristic modes of failure are described. The systems and components discussed in this Phase I report consist of those installed as original equipment on new 1972 and subsequent model-year engines and vehicles. A list of the components determined to be emissions-related is presented at the end of this section.

3.1 CRITERIA AND ASSUMPTIONS

Emissions-related systems, parts, and components were defined by the study contract to be emissions-related if they had to be built to certain specifications and/or perform within certain specifications, or one or more pollutant (HC, CO, NO_x, smoke) would exceed applicable standards for the vehicle or engine. This definition was sufficiently broad to include essentially all engine and emission control systems used on vehicles.

For the purpose of this study, "original equipment" included all systems, parts, and components installed in new vehicles and engines by or for the vehicle or engine manufacturers in compliance with regulations issued under Title II of the Clean Air Act. Under this contract original equipment also included those replacement parts which were identical to factory installed components and were built by or for the vehicle or engine manufacturer. To simplify the analysis, this definition was interpreted to mean all replacement parts or components distributed by the original vehicle/engine manufacturers through their dealer or authorized service center networks.

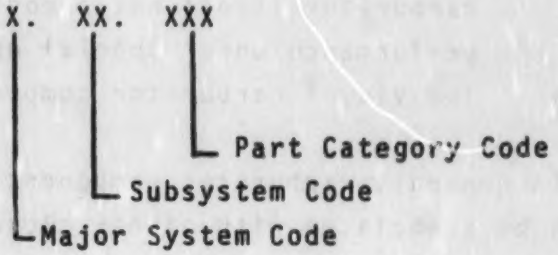
Although the contract defined emissions-related parts to be those whose failure would cause violation of emissions standards, it was not possible to determine from the literature or engineering analysis if all of the component defects would cause an emissions failure. This was because even though emissions might be doubled, low emitters might still pass the standard. Therefore, rather than arbitrarily exclude a component from further consideration because its failure was assumed not to cause emissions failure, all components with potential effects on emissions were considered. This included components whose failure affected the operation of other components.

To facilitate the analysis, individual parts with similar design and function were grouped together into part categories (i.e.; spark plugs, air filters, thermal vacuum valves, etc.). Individual components within each part category were then assigned average parameter values representative of typical components included in that category. Assignment of specific values for each input parameter is described in Section 4.

In order to assign specific values to the input parameters, it was necessary to define a typical failure mode for components in each category. For most components, individual design, fabrication, assembly, and application characteristics could differ depending on manufacturer and model resulting in a different failure mode or failure threshold for individual components within each category. However, since the scope of this study could not include all individual components, it was necessary to select representative components from each category and to define the characteristic failure modes for that component.

Several component categories within emission control systems use similar components (i.e.; thermal vacuum switches, vacuum hoses, speed/transmission sensors). These components were assigned identical failure modes and probabilities of failure even though they were used in different applications. Emissions increase and probability of repair factors may have been different, however, depending on the application.

Engine and emission control components are functionally or physically related to other specific components. This permitted the grouping of related categories of components into subsystems and major functional systems. Each system and its component parts were assigned a part code number based on the following system:



The part code system provided a systematic method of compiling and processing the data. The relationship of emissions to the following major systems and their respective components are discussed in this Section:

- Carburetion system
- Ignition system
- Air induction system
- Fuel injection system
- Miscellaneous engine systems
- Emission control systems

The literature surveyed in Section 2 and an engineering evaluation formed the bases for the discussion presented below.

3.2 CARBURETION SYSTEM

The carburetion system is responsible for correctly metering the required amount of fuel to the engine. Carburetion systems depend upon relatively complex mechanical and vacuum controls which, if defective, can severely impair the functioning of the overall system. For purposes of this study, the carburetion system was divided into the following three subsystems:

- Complete carburetor assemblies, either new or rebuilt.
- Carburetor control devices external to the carburetor itself which modify the carburetor performance under special operating conditions.
- Individual carburetor components.

In general, carburetor components and control devices can be associated with either closed-throttle (idle) or open-throttle (acceleration or cruise) operation. The certification test for light-duty vehicles (1972 FTP and 1975 FTP) contains substantial idle operation. However, defects in cruise or power circuits can result in very high mass emissions due to the high exhaust flow rate under these operating conditions. The certification test results are also highly dependent on cold start emissions and rapid warm-up. Therefore, defects which result in delayed or improper choke opening can cause substantial emission increases.

Carburetion system defects generally result in excessively rich operation which leads to high CO emissions and occasionally high HC if the CO increase is severe enough. Typical defects resulting in rich operation include the following (Ref. 2 and 3):

- Improper choke setting or rate of opening.
- Ruptured power valve (economiser) vacuum diaphragm.
- Worn or improperly set metering rods.
- Improperly set or defective float and needle valve.
- Improper idle adjustment.
- Defective idle stop solenoid, throttle positioner, or dashpot.

Some component defects can cause lean operation resulting in misfire (Ref. 2 and 3). The misfire may be detected by performance (stumble and hesitation) or by excessive HC emissions. These components include:

- Worn accelerator pump plunger.
- Ruptured accelerator pump vacuum diaphragm (if equipped).
- Worn or broken gaskets.
- Ruptured vacuum diaphragms.
- Improper idle adjustment.
- Improperly set float level.
- Improperly set metering rods.
- Restricted fuel filter.

In general, defects leading to rich operation are associated with open-throttle conditions and contribute high mass emissions. Exception to this include grossly rich idle mixture. Defects leading to lean operation tend to be associated with closed-throttle conditions (i.e., high manifold vacuum) which are intermittent and contribute low mass emissions. Therefore, defects in carburetor components causing rich operation generally result in substantial CO mass emission increases while components causing lean operation usually result in marginal HC mass emission increases.

The effect of carburetor defects on NO_x emissions are inversely related to the effect on CO emissions (Ref. 2). Rich operation resulting in high CO will generally result in reduced NO_x. Lean operation resulting in high HC may also result in increased NO_x due to higher combustion temperatures and mass flow rate because the throttle must be held open further to compensate for the power loss resulting from misfire. However, since conditions where lean misfire occur are usually intermittent or at closed throttle, the effect on NO_x may be negligible.

3.2.1 Complete Carburetors

Complete carburetors, either new or rebuilt, are sold ready for installation on the vehicle. All necessary interface and accessory components, including gaskets, dashpots, choke, and throttle linkage are generally provided with the carburetor. Considerable data has been generated which indicates that the metering accuracy and reliability of new carburetors built and distributed as OEM or OEM-replacement carburetors are generally better than factory rebuilt carburetors or carburetors repaired by mechanics. Therefore, separate part categories have been defined for OEM (new) and after-market (rebuilt) carburetors.

Carburetor performance can affect all three pollutants, although CO is usually most sensitive to defects or improper adjustment. Gross carburetor malfunction is usually associated with one or more of the following components (Ref. 2, 3, 16, 78, and 27):

- Choke
- Power valve
- Metering jets and rods
- Float adjustment
- Accelerator pump
- Idle adjustment
- Gaskets

Other components can also increase CO emissions under certain operating conditions or circumstances. The actual impact of each defect depends on the engine and carburetor under consideration.

Since each of the above components is individually repairable, they have been treated individually in this study.

3.2.2 Carburetor Control Devices

Several emission control devices have been developed to regulate or modify the carburetor's operation under certain operating conditions. These devices generally regulate throttle closure in such a way as to modify the normal fuel-metering characteristics of the vehicle. Defects in these devices can increase HC and CO emissions but the increases are generally not as severe as from fundamental carburetor defects.

3.2.2.1 Idle-Stop Solenoid

The idle-stop solenoid is used on most 1972 and later model-year vehicles. The idle-stop solenoid is a two-position electrically-operated valve, used to provide a predetermined throttle setting. The solenoid becomes energized when the ignition key is turned on. When energized, the plunger extends and contacts the carburetor throttle lever preventing full closing of the throttle plates. When the solenoid is de-energized (plunger retracted), the throttle plates close beyond the normal idle position. This action shuts off carburetor air supply, starving the engine so that it will shut down without dieseling (Ref. 3 and 27).

For precatalyst-equipped vehicles, the idle-stop solenoid is primarily a performance-related device to ensure that the lean calibrated carburetors used in these model-years did not promote dieseling of the engine and subsequent customer complaints. However, for catalyst-equipped vehicles, the idle-stop solenoid becomes important as a catalyst protection device to prevent excess fuel flow and subsequent catalyst overheating during engine shut down (Ref. 27).

Defects in the idle-stop solenoid would involve shorted or open windings in the solenoid which prevent extension of the plunger. This would prevent opening of the throttle causing slow and rough idle. Excessive throttle opening and throttle operation by the driver would be required to maintain satisfactory idle performance. This defect would increase HC and CO emissions during closed throttle operation.

3.2.2.2 Throttle Dashpot

The throttle dashpot is generally used on imported vehicles and some domestic vehicles with manual transmission. The dashpot is a mechanical device which acts as a damper to prevent too rapid throttle closure. This device can be used to prevent stalling and/or to reduce emissions by reducing the momentary rich condition caused when a throttle is closed rapidly (Ref. 3 and 27).

Failure of the dashpot is usually due to deterioration of seals. This results in too rapid throttle closure leading to higher HC/CO emissions during deceleration.

3.2.2.3 Throttle Positioners

Throttle positioners are used to hold the throttle slightly open during deceleration to provide a more combustible mixture to the engine and, thus, reduce emissions. An additional control device is generally provided to allow the throttle to close to normal idle position after a certain length of time, or when vehicle speed decreases to a certain point. These devices are usually operated electrically but may be vacuum operated (Ref. 3 and 27).

Throttle positioners are active devices which perform a function similar to the passive dashpot described in the preceding paragraph. Throttle positioners are used on some domestic and foreign vehicles for improved HC/CO emission control. They can be regulated more precisely than dashpots using electrical sensors for speed, temperature, vacuum, etc.

Failures of the electrically operated throttle positioner are similar to the idle-stop solenoid. If vacuum operated, failures are generally associated with ruptured diaphragms. Both failures result in normal closed throttle operation during all temperature and speed conditions. Temperature and speed sensors for the throttle positioner are usually associated with systems to modify timing and are discussed under TCS or EGR.

3.2.3 Carburetor Components

The following carburetor components are grouped together because they can be clearly distinguished as separate components, are readily replaceable, and are routinely adjusted or repaired by mechanics. A carburetor malfunction is generally attributable to a defect or maladjustment of one or more of these components.

3.2.3.1 Metering Jets

Metering jets are calibrated orifices through which fuel passes in response to the vacuum created by the carburetor venturi. The metering jet may be located in the venturi or near the float chamber. The jets generally control fuel metering from about 1/4-throttle opening to about 3/4-throttle opening. Over extended periods of operation, the throttle jet can erode due to the passage of fuel resulting in fuel enrichening (Ref. 2 and 3). This results in increased CO and possibly HC emissions.

3.2.3.2 Metering Rods

Some carburetors use metering rods instead of, or in addition to, metering jets. The metering rod is a variable diameter rod which moves in and out of the jet to cause different effective orifice sizes. The metering rod is, therefore, better able to control fuel metering to variations in throttle position or vacuum. Metering rods are moved by mechanical linkage to the throttle or by vacuum diaphragms.

Metering rod accuracy is strongly related to position of the rod in relation to the load condition. Rod position determines fuel metering at the particular throttle opening. Therefore, the characteristic defect defined for metering rods will be incorrect positioning, resulting in excessive metering of fuel at all off-idle load conditions. This results in higher CO and possibly HC emissions (Ref. 2, 3, and 27).

3.2.3.3 Vacuum Break Valves

Vacuum break valves, also called vacuum kick or choke pull down valves, are used on most carburetors to modulate the choke position. The basic choke position is determined by the choke thermostat as described in paragraph 3.2.3.4. The vacuum break valve is used to adjust the choke position to suit actual load condition as reflected by vacuum. Under high vacuum (i.e., idle), the vacuum break valve opens the choke slightly to gradually lean out mixture as soon as the engine starts. However, at low vacuum (i.e., open throttle and moderate load), the vacuum break valve will again close the choke so that a richer mixture during the heavy load is provided to prevent stalling.

Defective vacuum break valves will result in normal choke opening causing higher CO emissions. The typical failure mode is a ruptured vacuum diaphragm. This may result in lean misfire at idle due to a vacuum leak, as well as the overall rich condition (Ref. 2, 3 and 27).

3.2.3.4 Choke Thermostat and Linkage

All carburetors employ a choke which restricts airflow into the engine during cold starts. Since emission control is very dependent on correct choke operation, automatic chokes have replaced manually-operated chokes on most emission-certified vehicles. The automatic choke is activated by a thermostatic coil spring which unwinds as heat is applied. As the spring unwinds, it causes the choke valve or plate to open permitting proportionally more air to enter the carburetor. The fully-open choke does not restrict airflow and, therefore, normal fuel metering is accomplished by the idle and cruise circuit of the carburetor.

Choke failures are often due to sticking linkages which cause the choke to remain either open or closed. An open choke will cause poor starting, idle running, and driveability during cold starts and will usually be corrected. A closed choke may cause excessively rich mixtures (10 percent CO), particularly under part throttle loaded operation, and may not be detected by driveability problems. Very rich mixtures can also cause moderate increases in hydrocarbon emissions (Ref. 2, 3, 16, 78, and 103).

Other choke failures may be due to broken choke springs, incorrect choke adjustment, defective vacuum break unit, or defective choke heater (Ref. 3).

3.2.3.5 Accelerator Pumps

The accelerator pump is used on nearly all carburetors and provides a quick burst of fuel during rapid acceleration. Without the accelerator pump, the mixture would lean out and possibly cause intermittent lean misfire as shown by hesitation or stumbling performance. The accelerator pump consists of a mechanically- or vacuum-operated plunger, check valves, and metering jet. The accelerator pump can cause excessively rich operation and high CO emissions if it is improperly adjusted or if there are defects or wear in the check valves, metering jet, or vacuum diaphragm. However, the probable defect of the accelerator pump will be diaphragm failure (vacuum-operated pump) or pump piston seal wear. Both situations will reduce the effectiveness of the pump action leading to lean out and possibly lean misfire and stumble during acceleration. This will increase HC mass emissions (Ref. 2, 3 and 27).

3.2.3.6 Power Valves

The power valve, or economiser valve, provides additional fuel through the high speed circuit for full power operation at wide-open throttle. The power valve is vacuum-, or in some cases, mechanically-operated. Not all carburetors, however, are equipped with true power valves. Some carburetors only use metering rods (Section 3.2.3.2) which provide more fuel to the high speed circuit at wide-open throttle (Ref. 2, 3 and 27).

Power valves open in response to low manifold vacuum during open throttle operation. During closed or part throttle operation, the manifold vacuum increases, pulling the power valve closed. Any obstruction in the vacuum passages or rupture of the vacuum diaphragm causes the power valve to remain open at all times and meter excessive fuel under off-idle operation. The characteristic defect of power valves are, therefore, ruptured vacuum diaphragms leading to high CO mass emissions (Ref. 2 and 3).

3.2.3.7 Gaskets

Gaskets are used to join the carburetor to the manifold and to join together the individual assemblies of the carburetor. The gaskets provide an air seal against the engine intake vacuum. Gaskets are subject to thermal and mechanical deterioration. Periodic tightening of the carburetor mounting bolts are recommended by most manufacturers to compensate for gradual compression of the gaskets (Ref. 3 and 27).

Air leaks past defective gaskets can result in lean misfire and high HC emissions. In some cases, internal gaskets can be eroded by gasoline and fuel enrichening can occur. Gaskets have complex shapes and can be installed improperly during assembly or repair of the carburetor. However, vacuum leaks past defective gaskets are the most likely failure mode (Ref. 3).

3.2.3.8 Rebuilding Kits

Rebuilding kits for carburetors normally include gaskets and replacement parts subject to wear such as needle valve and seat, power valve and accelerator pump diaphragms, dashpot, and small springs and connectors. Rebuilding kits are considered an after-market component in this study even though some kits are distributed by the automobile manufacturers.

Rebuilding kits should normally return a carburetor to "like new" condition. However, considerable experience has shown that a large percentage of carburetors rebuilt by vehicle owners or mechanics using kits did not operate correctly. This is generally due to improper or incomplete cleaning of air bleed passages in the carburetor or incorrect installation of gaskets or other components. Improperly rebuilt carburetors can have high CO and HC emission (Ref. 16, 33, and 78).

3.2.3.9 Float and Valve

The float and valve assembly serve as the fuel reservoir for the carburetor. All the jets (idle, main, and power circuits) are fed with fuel from the float chamber. The rate of fuel metering by all circuits depends on the height of the fuel column which, in turn, is controlled by the float in the carburetor bowl. The needle valve for the fuel inlet is connected to the float so that additional fuel is admitted to the reservoir as the float drops (Ref. 2, 3 and 27).

Over long periods, the float may develop leaks or the needle valve and seat may wear so that excessive fuel may be admitted to the reservoir. This will result in rich operation and excessive CO emissions under all operating conditions. The float is subject to adjustment and may be set incorrectly either during assembly or during repair or rebuilding (Ref. 2, 3, and 78).

3.2.3.10 Idle Adjustment

Setting idle mixture is a fundamental tune-up step which is usually specified, although not always performed. Idle adjustment affects idle HC and CO emissions. Low idle emissions tend to give lower FTP emissions although statistical correlation between the measurements is poor (Ref. 60 and 84). The idle adjustment usually regulates bypass (bleed) airflow which is introduced below the closed throttle plate to mix with idle fuel flow. The idle mixture screws provide a convenient method to adjust each vehicle for optimum idle operation under actual operating conditions. It also provides compensation for clogged or restricted idle air or fuel jets (Ref. 2 and 3).

The idle emissions are poorly correlated to FTP emissions because most of the mass flow of the FTP emissions are provided by the main or power valves. Therefore, the idle mixture may be lean while the FTP emissions are high due to choke or power valve defects. Similarly, the idle mixture may be excessively rich but the FTP emissions satisfactory because of lean cruise operation. Inspection and maintenance studies, however, show that most vehicles with incorrect idle adjustment are set rich resulting in high CO and, in some cases, high HC emissions (Ref. 12, 16, 33, 74, 90, 94, and 99).

3.2.3.11 Idle Enrichment System

The idle enrichment system, used on a few engines, provides additional vacuum-operated choking during cold starts. This system consists of an air bleed on the carburetor which is closed by a solenoid and a thermal vacuum valve. The thermal vacuum valve responds to coolant temperature to disable enrichment during hot starts. The solenoid valve is activated by the starting circuit and a timer which holds the solenoid open for 35 seconds. This system was utilized to prevent engine stalling while cold. Failure of the system is most likely to defeat the enrichment process. Therefore, an increase in HC emissions might result from the system due to lean misfire when cold (Ref. 27).

3.2.4 Fuel Filter

The fuel filter is used to remove any entrained particles and dirt in the fuel. If the filter was missing, foreign particles could lodge in the fuel metering passages of the carburetor and affect operation. By itself, however, the fuel filter does not have a significant impact on emissions unless it becomes so clogged as to restrict fuel flow (Ref. 2 and 3). Under this condition, the fuel filter could result in excessive HC emissions due to misfire. Although unlikely, this has been observed in some surveillance and inspection/maintenance programs. Therefore, the failure mode for fuel filters is flow restriction leading to lean misfire.

3.3 IGNITION SYSTEM

Ignition component defects are generally related to increased HC emissions resulting from misfire (Ref. 12, 16, 33, 74, 78, and 100). In some cases (i.e., distributor advance mechanisms), the component performance may affect NO_x because of changes in ignition timing (Ref. 17, 92, and 98). Specific individual components within each category do not have identical design or performance characteristics. However, the general component descriptions, functions and modes of failure are presented below for the following ignition system components:

- Points
- Condenser
- Distributor cap
- Distributor rotor
- Mechanical advance

- Vacuum advance
- Distributor drive
- Dual diaphragm distributors
- Spark delay valve
- Magnetic/Optical triggers
- Spark plugs
- Ignition wires
- Coils
- Capacitive discharge systems
- Ballast resistor
- Electronic ignition circuits
- Glow plug
- Ignition timing adjustment

These components are generally grouped into primary (low voltage) or secondary (high voltage) circuits. In general, secondary ignition components (spark plugs, wires, distributor cap and rotor) cause misfire in specific cylinders. Complete misfire on one plug may be due to a fouled plug or shorted ignition wire. Intermittent misfire, which is more likely, can occur under certain operating conditions depending on plug gap and condition, mixture richness, wire resistance, and engine speed. Intermittent misfire may not be noticeable by the driver but may cause increased HC emissions. The emissions increase depends on the number of cylinders, misfire frequency, engine speed, and whether air injection and catalytic emission control system are present.

Primary ignition components include points, condenser, advance mechanisms, coils, capacitive discharge systems, ballast resistors, and electronic ignition components. Primary ignition system defects may cause random intermittent misfire on all cylinders. However, in practice, misfire will characteristically appear on the cylinder with the weakest secondary ignition components. Misfire is caused by faulty coil, points, and electronic ignition components.

because insufficient voltage and current is supplied to the spark plug. High HC emissions can also be caused without actual misfire if the timing of spark plug firing is incorrect (Ref. 16, 17, 92, and 99). In these cases, the advance mechanisms, basic timing, or distributor cap/rotor may be faulty.

3.3.1 Points

The points constitute a switch which energizes the primary circuit of the coil. As the points make contact, current flows through the coil creating a magnetic field. As the points open, the current flow stops and the magnetic field collapses creating a high voltage surge in the secondary system. The points wear mechanically and may also erode electrically due to improper alignment, polarity, or condenser capacitance. As the gap between the points open, they may no longer make sufficient contact to adequately charge the coil. The low voltage may then cause intermittent misfiring of the spark plugs and increased HC emissions (Ref. 2 and 3).

3.3.2 Condensor/Capacitor

The condenser is a capacitor which prevents an electrical arc across the points as they open. The condenser absorbs the current flow until the points are fully open. Arcing of the points results in an electrical erosion or transfer of material from one point to the other. Condensers normally are very durable but are routinely replaced as a preventative step at each tune-up. They are emissions-related because of their effect on coil and point life (Ref. 3).

3.3.3 Distributor

The ignition distributor controls the making and breaking of the primary ignition points and distributes the high voltage current to the proper spark plug at the correct time. Detailed construction of distributors varies considerably between manufacturers. Basically, however, each can be divided into the following categories:

- Cap
- Rotor
- Mechanical advance
- Vacuum advance
- Distributor drive
- Dual diaphragm distributor
- Spark delay valve.

3.3.3.1 Cap

The cap provides terminals for connecting the spark plug wires and the rotor contact. The terminals in the cap are subject to corrosion, wear, and electrical erosion due to arcing. This deterioration can reduce the peak voltage and duration of the secondary current. It is also possible for conductive trails to be formed between contact terminals of the cap resulting in crossfiring of the wrong spark plug. Either situation causes intermittent misfire, thereby, increasing HC emissions (Ref. 2 and 3).

3.3.3.2 Rotor

The rotor is a rotating conductor which distributes the high voltage current to the correct spark plug by contacting the corresponding terminal in the base of the cap. The contact terminal of the rotor is subject to wear and erosion as are the terminals of the cap. As the rotor wears, the resistance of the circuit increases which reduces peak voltage and firing time. These, in turn, may result in misfire and excessive HC emissions (Ref. 2 and 3).

3.3.3.3 Mechanical Advance Mechanism

The mechanical advance mechanism, also called centrifugal advance, regulates the time at which the points open and close relative to the position of the piston in the cylinder. The mechanical advance provides an earlier spark firing at high rpm because the time available to burn the charge is shorter at high speed than low speed. The advance mechanism consists of two weights held by springs which are thrown outward from the distributor shaft by the centrifugal force of the rotating distributor. The faster the distributor shaft rotates, the greater the movement of the advance weights. The movement of the weights rotates the breaker plate containing the points and changes the time at which the points make contact. The mechanical advance unit is very durable and generally does not need to be replaced or serviced over the life of the vehicle. However, failure of the advance mechanism can occur due to broken or weakened springs which will alter the ignition timing and affect HC and NO_x emissions (Ref. 2 and 3).

3.3.3.4 Vacuum Advance Mechanism

The vacuum advance mechanism provides the same function for vacuum as mechanical advance does for engine speed. The intake manifold vacuum is transmitted to a diaphragm connected to the breaker plate. The diaphragm is spring-loaded and airtight on one side, and open to the vacuum line on the other. As vacuum increases, the diaphragm deflects and moves the breaker plate via connecting linkage (Ref. 3).

The ignition advance affects both HC and NO_x emissions (Ref. 16, 17, and 99). Because vacuum advance can be easily modulated by controlling the vacuum signal, vacuum control valves are an integral part of emission control systems. In general, vehicles manufactured after 1972 have used modulated vacuum advance as part of the NO_x control system. The systems and components which control vacuum are discussed in the section on emission control systems.

Vacuum advance systems fail more frequently than mechanical advance due to fatiguing of the diaphragm and subsquent failure to correctly adjust timing to vacuum changes (Ref. 78).

3.3.3.5 Distributor Drive Mechanism

The distributor drive consists of the distributor shaft, cam, and breaker arm. The distributor shaft is connected directly to the engine and is driven at 1/2 the engine rpm. The distributor shaft rotates the cam which has one lobe for each cylinder. The breaker arm is held against the cam by spring tension. As the cam rotates, the breaker arm rides in and out on the lobes. The point mounted on the breaker arm then makes and breaks contact with the stationary point (Ref. 3).

Mechanical wear of the distributor shaft, bearings, bushings, cam lobes, and breaker arm all cause deviation from specification of point opening and closing. The deviation may be consistently on one cylinder (defective cam lobe) or randomly on all cylinders (defective bearings). This deterioration can result in intermittent misfire and excessive HC emissions (Ref. 3).

3.3.3.6 Dual Diaphragm Distributor

Some vehicles are equipped with dual diaphragm distributors which are similar to standard distributors except that two vacuum advance diaphragms are provided. This distributor allows the spark timing to be retarded in a normal manner during starting. During acceleration and part throttle cruise, the spark timing is advanced in a normal manner. However, during idle and deceleration, the timing is retarded even more than would normally occur. This provides HC emission control during idle and deceleration by encouraging higher engine rpm and smaller quench volume in the cylinder at the time of spark firing. Failure of either diaphragm will effect emissions of HC and CO (Ref. 3 and 27).

3.3.3.7 Spark Delay Valve

The spark delay valve, used on some engines, aids in control of HC and NO_x emissions by delaying vacuum spark advance during light acceleration. Immediate spark retard is still permitted during deceleration. The valve controls vacuum by means of an integral sintered metal disk and check valve. The delay valve is connected in the vacuum line between the carburetor spark port and advance diaphragm of the distributor. Several different valves are used which provide slightly different delay times depending on engine application. Failure of the valve occurs when the check valve fails to seal. In these conditions, normal spark advance is provided which can increase HC and NO_x (Ref. 2, 3 and 27).

3.3.4 Magnetic or Optical Triggers

Electronic ignition systems use either magnetic proximity detectors or photodiodes to indicate the correct firing time of each spark plug. OEM systems generally use magnetic systems. Some after-market systems which directly replace the standard breaker points use optical detectors. The magnetic or optical triggers are rigidly mounted on a breaker plate connected to the vacuum advance unit. The distributor cam is replaced by either magnetic or opaque bars mounted on the distributor shaft. One bar is provided for each cylinder. As the distributor shaft rotates, the bars move past the magnetic pickup or block a light beam between a lamp and photodiode. The magnetic or optical pickup then generates a signal pulse which is sent to the electronic ignition control circuit (Ref. 3 and 46).

The alignment of the ignition triggers is critical in these systems, but there is little wear or deterioration. Problems can still develop in the distributor drive or vacuum advance mechanism, however, since they are identical to standard units.

Failures of the electronic triggers are unlikely and would probably disable the vehicle. It is possible, however, for deterioration in a detector to cause an intermittent misfire due to failure to detect one of the bars. This is analogous to a faulty distributor cam and results in increased HC emissions.

3.3.5 Spark Plugs

Spark plugs provide the gap in the cylinder across which the high tension voltage arcs. The resulting spark ionizes the charge between the electrodes of the spark plug igniting the combustion process. A variety of spark plugs are manufactured with varying electrical, thermal, and physical characteristics. Selection of the correct spark plug is important since accelerated fouling or deterioration of the plug can occur if it is not suited to the application.

Spark plugs significantly affect HC emissions due to intermittent or total misfire of the air-fuel mixture. Spark plug performance depends on gap width which is dependent on thermal and electrical erosion. Fouling which can be caused by carbon residue, lead residue, or oil also affects plug performance (Ref. 2, 3, 16, 42, 43 and 78).

Spark plugs are routinely replaced as a preventative measure every 12,000 miles or 12 months. Some manufacturers of 1975 and later model-year vehicles, however, now recommend longer replacement intervals because factors responsible for plug fouling, such as lead deposits, have been modified as part of catalyst and high voltage ignition system design.

3.3.6 Ignition Wires

Ignition wires conduct the current from the distributor cap to the spark plug. Ignition wires are subject to thermal and mechanical deterioration which either increase their internal resistance or decrease the effectiveness of their insulation. Both effects reduce the current and voltage available at the spark plug. The reduced voltage then causes reduced spark intensity and intermittent or total misfire. Misfire will usually occur under load when the high frequency of coil charging results in lower average available voltage to all spark plugs. Crossfire or firing of a cylinder at the wrong time, can also result if two wires cross and touch each other at a point where their insulation is defective (Ref. 3 and 78).

3.3.7 Coils

The coil is the OEM high voltage source on most vehicles. The coil is a pulse transformer designed to step up the primary (12V) voltage to the high (20,000V to 40,000V) voltage required to fire the spark plug. Failures of the coil result in low available voltage to the spark plug and may result in intermittent misfire particularly at high speed (Ref. 3, 35 and 78).

3.3.8 Capacitive Discharge Systems

Capacitive discharge (CD) ignition systems are sold for after-market, high performance applications. A few high performance sports cars, however, are OEM-equipped with CD ignitions. The CD ignition provides high secondary voltage with very fast rise time. The spark gets to the plug faster, and although the voltage is higher, the spark duration is shorter which extends plug life. The higher voltage also is better able to fire fouled plugs than the standard ignition system (Ref. 3).

The CD system may utilize either electronic or breaker point timing. A transformer is used to step up the primary voltage to several hundred volts which is then discharged through a standard ignition coil using a capacitor switch. The higher primary voltage permits lower primary current flow which extends point life if points are used. The coil is able to output a higher secondary voltage which is then distributed to the cylinders by a conventional distributor (Ref. 3).

Because CD ignition systems have such limited OEM usage, they will be included in Phase II, the after-market parts, analysis only.

3.3.9 Ballast Resistor

In most ignition systems, one and sometimes two resistors are used. In standard breaker point systems, the resistor is in series with the coil during normal operation. However, during cranking when the starter motor load reduces the available voltage, the resistor is bypassed. The resistor, therefore, simulates the starter motor load and ensures that the coil is exposed to consistent primary voltages. A defective resistor will disable the engine, either through an open circuit or by rapidly burning out the coil. A resistor with low resistance can also result in burned points (Ref. 2 and 3).

Electronic ignition systems usually use two resistors, one for the coil and a second one for the electronic switching circuits. The coil resistor maintains stable voltage at the coil and output of the power transistor. The starting resistor performs the same function described above for the ballast resistor in a standard ignition system (Ref. 3).

3.3.10 Electronic Ignition Circuits

The switching and amplifying circuits of electronic ignition systems take the low level signal from the magnetic or optical triggers and provide a 5 to 10V signal to the ignition coil. The electronic ignition circuits are generally reliable and not subject to deterioration unless other components in the electrical system become defective. The electronic circuits will disable the vehicle if they fail; therefore, these components are not emissions-related (Ref. 3).

3.3.11 Glow Plug

The glow plug, used in diesel engines, is a resistor coil which becomes hot enough to act as an ignition source for compression ignition engines. The glow plugs are turned on prior to starting a cold engine and allowed to heat the cylinders for several minutes. The engine can then be easily started. Without a glow plug, the engine might not start when cold. The glow plug, if defective, can result in excessive emissions of unburned fuel and smoke during cranking and warm up. However, the heavy-duty diesel test procedures are conducted with the engine fully warmed up so that the glow plug is not emissions-related in terms of exceeding emission standards (Ref. 2 and 3).

3.3.12 Ignition Timing Adjustment

Basic ignition timing controls the moment at which the spark plug fires. Timing is adjusted at a specified idle engine speed and is expressed in crankshaft degrees before or after top dead center in the number one cylinder. Timing affects performance, emissions, and fuel economy because different combustion conditions occur as timing changes. In general, advanced timing causes the spark to fire earlier in the compression stroke. This usually increases HC (larger quench surface), reduces CO (longer burning time), and increases NO_x (higher mixture temperature and pressure). Retarded timing generally causes the spark to fire during the power stroke at or after top dead center. This usually reduces HC (smaller quench surface), increases CO (shorter burning time), and decreases NO_x (lower mixture temperature and pressure). Exhaust treatment systems may modify the measured exhaust emissions by thermal or catalytic oxidation (Ref. 2, 3, 16, 17, 21, 60, 78, 92, 93, 95, 96, 97 and 98).

Timing adjustments must be made carefully to ensure that the intended setting is actually achieved. This includes disconnecting vacuum lines from the distributor, ensuring that idle speed and mixture adjustments are correct, measuring timing correctly, setting the timing to the correct specification, and locking the adjustment without altering it. The chance of incorrectly setting timing is, therefore, fairly high (Ref. 2, 3 and 27).

3.4 AIR INDUCTION SYSTEM

The air induction system includes the air cleaner, air cleaner housing, manifolds, superchargers, turbochargers and associated hoses, ducts, pumps, and vacuum and electrical controls. The air induction system can have significant impact on the air-fuel ratio and, therefore, emissions of CO, smoke and, to a lesser degree, NO_x and HC.

3.4.1 Thermostatically Controlled Air Inlet

Thermostatically controlled air (TAC) inlets preheat cold air to promote better fuel mixing and vaporization. The specific design varies according to manufacturer. However, each system uses some or all of the following components:

- Shroud and heated air hose or duct
- Thermostat
- Vacuum hoses
- Fresh air inlet

Failure of the TAC shroud, hose, thermostat, vacuum motor or vacuum hoses will generally result in loss of heated air during warm-up. This will have the effect of reducing the vaporization of fuel and of increasing the mean air density during warm-up (Ref. 2). Both effects will tend to cause lean misfire and increased HC. The vacuum hose failure will also result in a vacuum leak which would be present at all operating conditions and would be expected to further increase HC emissions. The fresh air inlet on some vehicles extends the snorkel to the grill. This provides uniformly cool air in spite of overheating of the underhood air which could occur during prolonged idle. This maintains proper air-fuel ratios by controlling the air density (Ref. 3 and 27).

3.4.1.1 Shroud and Hose

Cold air is heated by passing it near the exhaust manifold. The shroud is a sheet metal enclosure which covers the exhaust manifold and directs air along it. The duct or hose connects the shroud to the air cleaner. The duct and shroud may become damaged due to maintenance on the vehicle which requires removal of the air cleaner. This will probably result in increased HC emissions during the cold start.

3.4.1.2 Thermostat

The thermostat is mounted in the air cleaner assembly and controls the opening and closing of a damper which is used to select either underhood air or preheated air from the shroud. The thermostat senses incoming air temperature and if it becomes too low, will direct preheated air into the carburetor. The thermostat may be directly linked to the hot air valve or it may be connected to a vacuum switch. Failure of the thermostat may occur in either position but is more likely to be stuck open since this is its usual position. This will prevent heated air from entering the carburetor and have the same effect as a damaged hose.

3.4.1.3 Vacuum Motor and Hoses

Some systems use vacuum motors to operate the hot air valve. The vacuum signal originates at the manifold and is transmitted to the vacuum motor by standard vacuum hoses. The hoses are subject to thermal and mechanical deterioration. The vacuum motor is a diaphragm which moves when vacuum is applied and is returned by a spring to its original position when vacuum is removed. The vacuum motor is reliable but is subject to the same diaphragm failures as any other vacuum activated device. Failure of the vacuum motor or hoses would result in the engine always receiving cool air and would also introduce a manifold vacuum leak when the motor would normally be activated; i.e., cold start.

3.4.1.4 Fresh Air Inlet

Beginning with some 1975 model-year vehicles, the fresh air inlet to the carburetor was moved from the carburetor air cleaner assembly to the radiator grill. A flexible, reinforced paper duct is used. This provides a ram jet effect to counteract the characteristic of carburetors to enrichen the mixture at high airflows. The air available at the radiator is also somewhat colder and, therefore, more dense than underhood air, particularly during low speed operation when air movement in the engine compartment is restricted. The fresh air inlet is subject to mechanical and thermal deterioration, especially when inspecting or servicing the carburetor. Failure of the inlet duct would result in hotter underhood air being drawn into the engine resulting in slight enrichment and increased CO emissions.

3.4.2 Air Cleaner Element

The air cleaner removes particulates in the incoming air and, in some applications, must also remove entrained oil droplets or exhaust particulates from the PCV system. The filter element eventually becomes clogged with material and does not allow sufficient air into the carburetor. This results in fuel enrichening and excessive CO and possibly HC emissions (Ref. 2, 3, 12, 16, 78 and 100).

3.4.3 Manifolds

The intake manifold generally is not changed on a vehicle except for unusual cases of manufacturing defects or to perform after-market, high performance modifications. Intake manifolds connect the carburetor to the cylinders and provide the ducts to introduce the air-fuel mixture into each cylinder. Some mixing of air and fuel occurs in the manifold although this is not subject to maintenance. The exhaust manifold connects the exhaust ports of the cylinders to the exhaust pipe. Specific control components of the manifolds (i.e.; heat risers, cross overs, EGR valves, and back pressure sensors), are discussed below under emission control systems. There is no specific emissions failure mode for an OEM manifold (Ref. 2 and 3). It is, therefore, excluded from the OEM criticality analysis.

3.4.4 Turbochargers

Turbochargers are turbine-driven blowers which pressurize the intake manifold in proportion to exhaust gas flow rate. This permits higher volumetric efficiency of the engine, particularly during acceleration. The turbocharger results in improved horsepower and may help to reduce emissions due to leaning out of the air-fuel ratio (Ref. 2 and 3).

Turbochargers are not currently used on OEM spark ignition engines but are available as retrofit kits for some after-market applications. Turbochargers are used on many OEM diesel engines for improved economy and power.

Failure of the turbocharger results in fuel enrichening due to reduced air intake which will cause increased smoke emissions from diesels or HC and CO emissions from gasoline engines (Ref. 2, 3, 37, 63 and 89).

3.4.5 Superchargers

Superchargers are belt-driven compressors which continuously pressurize the intake manifold. Superchargers are not available on OEM vehicles and are unusual for aftermarket installations because they represent a continuous load on the engine and do not provide significantly better performance than turbochargers (Ref. 2 and 3). Superchargers are, therefore, excluded from the OEM criticality analysis.

3.5 FUEL INJECTION SYSTEM

Some spark ignition and all compression ignition engines employ fuel injection systems which inject fuel into either the intake manifold or directly into the cylinder or its prechamber. Fuel injection systems provide more precise fuel metering than carburetors and, on diesels, are also needed to overcome the cylinder pressure occurring during the compression stroke when the fuel is injected (Ref. 2).

Fuel injection systems must fulfill the following basic functions:

- Meter the correct quantity of fuel for the speed and load condition.
- Inject the fuel at the correct time.
- Inject the fuel at the correct rate.
- Atomize the fuel into fine droplets.
- Distribute the fuel in the cylinder.

The specific design employed to accomplish these functions depends on the particular engine. The injection system may be mechanically or electrically controlled. In general, mechanically controlled systems are used in diesel engines and electrically controlled systems are used in gasoline engines (Ref. 2 and 3).

3.5.1 Accumulator

The accumulator is used on the common rail type of fuel injection system. It provides a damping reservoir in a high pressure system and does not have a specific failure mode (Ref. 3). The accumulator is not used on systems with return lines to the fuel tank.

3.5.2 Fuel Pump (High Pressure)

Except for manifold injection of gasoline and the unit injector system for diesel engines, all fuel injection systems utilize high pressure fuel pumps in the supply line. Fuel pumps are driven directly by the engine using accessory shafts. The pumps are positive displacement using either a gear pump or plunger and barrel design. Some pumps incorporate speed governors and idle adjustments. Fuel pumps are generally very durable and do not require adjustment or maintenance within the 50,000-mile service life (Ref. 2 and 3).

3.5.3 Fuel Pressure Sensors/Regulators

Regulators are used to ensure that the pressure of the fuel is constant at the injection valves or injectors. The regulators bypass excess fuel back to the fuel tank or to the low pressure side of the fuel pump. Fuel regulators are usually mechanical, spring-loaded devices. Pressure sensors connected to electronically controlled injection systems are used on some gasoline injection systems. Failure of the pressure regulators will usually result in higher than normal fuel pressure which is analogous to high float level in a carburetor (Ref. 2 and 3).

3.5.4 Throttle Linkage and Valve

Throttling of diesel engines is performed by regulating the quantity of fuel injected. The gasoline engine, however, is throttled by regulating the quantity of fuel and air. The throttle linkage and valve is not emissicns-related for gasoline engines. Throttling of the fuel injection system is controlled either at the high pressure pump or in the injector. The throttle linkage activates rotary valves which control the quantity of fuel admitted into the injectors. The valves are subject to wear which tends to increase the amount of fuel injected (Ref. 2 and 3).

3.5.5 Injection Valves

The injection valves consist of spring-loaded plungers which open when the fuel pressure exceeds the spring tension. The high pressure fuel then flows through the injector tips into the cylinder (Ref. 2 and 3).

The unit injector system uses a cam-actuated plunger and barrel assembly directly coupled to the injector tip. In this manner, all fuel supply lines are low pressure. Each cylinder has its own crank adjustment which throttles the fuel. This system is only used on direct cylinder diesel injection systems (Ref. 3).

Injection valves must be cleaned and adjusted periodically to ensure that they are metering the correct quantity of fuel. The injectors will tend to dribble fuel if foreign particles become lodged between the needle and seat. This results in excess HC, CO, and smoke emissions (Ref. 3 and 63).

3.5.6 Air Sensors/Switches

Air pressure (vacuum) or air flow rate sensors are used on some gasoline electronic injection systems to help control the correct air-fuel ratio. The sensors provide a signal which an electronic module uses to calculate the required quantity of fuel. The pressure sensors are reliable but are subject to diaphragm deterioration as in any vacuum sensing device. The air flow sensors may stick open indicating a high air flow rate incorrectly. Both defects will cause the EFI system to meter excessive fuel (Ref. 3, 27 and 58).

In addition to air flow sensors, exhaust oxygen sensors are also in use, or planned for use in conjunction with future three-way catalyst systems. The O_2 sensors generally have life expectancy similar to spark plugs. Their failure would usually result in excess fuel metering, although most systems have limited the degree of enrichment controlled by the O_2 sensor (Ref. 15 and 62).

3.5.7 Temperature Sensors/Switches

Sensors of air, water, or oil temperature are employed in gasoline injection systems to modulate the quantity of fuel injected. Some systems also employ temperature sensors to regulate air flow during cold starts or under idling conditions. Temperature sensors are generally reliable and free from wear or deterioration. Their failure, however, is analogous to a stuck choke and will cause high CO and possibly HC emissions (Ref. 3 and 58).

3.5.8 Fuel Distribution Manifold

Fuel distribution manifolds consist of the fuel distribution pipes connecting the fuel pump to the injectors. Fuel distribution manifolds may be either high or low pressure systems. Fuel distribution manifolds are not subject to wear or deterioration and are normally only replaced if physically damaged. Therefore, they are not considered in the OEM criticality analysis.

3.5.9 Injectors (Solenoid)

Electronic manifold fuel injection systems use solenoid-activated injectors. The solenoid is energized by an electronic distributor which provides the correct timing of the fuel flow. The injector is closed by a return spring when the solenoid is deactivated. The injector contains a calibrated orifice and needle valve which must be adjusted for precise fuel metering. The injectors are subject to the same problems as described in paragraph 3.5.5 for mechanically operated, direct cylinder injectors. The characteristic mode of failure is sticking which will inject excess fuel to one or more cylinders (Ref. 2, 3, 27 and 58).

3.5.10 Triggering Switches

Electronic fuel injection systems are operated by distributor contacts which control the timing and sometimes the duration of the opening of the injector valves. These contacts are similar to point contacts and are timed to coincide with intake valve opening. Trigger contacts are normally not adjustable; therefore, little maintenance is required. If the distributor shaft wears, however, the timing of the injection can become erratic which would increase emissions of HC and CO (Ref 3, 27 and 58).

3.5.11 Electronic Fuel Injection Control Circuits

Electronic fuel injection systems use electronic control circuits to modulate the frequency and duration of injector valve opening. The circuits utilize engine rpm, manifold vacuum, and air temperature to calculate the actual airflow, and corresponding fuel flow required to maintain the desired air-fuel ratio. These circuits are highly reliable and if they fail, will disable the vehicle. They are, therefore, excluded from the OEM criticality analysis (Ref. 2, 3 and 58).

3.5.12 Starting Valve

Both mechanical and electronic fuel injection systems employ starting valves. These valves provide additional fuel during cold starts and warm up. Mechanically-operated valves provide additional flow through the cylinder injection valves. Electrically-operated injectors in gasoline fuel injection systems provide additional fuel in the intake manifold. Failure of these valves will result in excessive CO and HC emissions if they continue to provide starting mixture enrichment after the engine is warmed up (Ref. 3).

3.5.13 Idle Adjustment Screws

The minimum flow rate of fuel through the injectors is controlled by idling screws. Depending on the design, these may be located in the fuel pump or at each injector. The screws require periodic adjustment and tend to increase flow rate with time. If not properly adjusted, they may result in higher emissions, although the effect is relatively small in comparison to component defects which cause overfueling during cruise operation (Ref. 2, 3 and 58).

3.6 ENGINE SYSTEMS

The mechanical components of the engine can also affect emissions, particularly as a result of wear and deterioration leading to misalignment. The engine system components which are emissions-related include the following:

- Exhaust valves and valve components such as lifters, cams, guides, and seals.
- Piston rings.
- Piston including piston, rod, head, and cylinder wall.
- Head gaskets.
- Camshafts.

3.6.1 Exhaust Valve Components

The exhaust valves seal the combustion chamber to prevent escape of hot combustion products until after the expansion stroke of the piston. The exhaust valves can become burned, misaligned, worn, or stuck, in which case unburned combustion products would be released. The components which affect the closing and sealing of the exhaust valves are discussed below.

3.6.1.1 Lifters and Springs

The valves are opened by push rods and lifters, and closed by springs. Changes in the physical dimensions or mechanical properties of either lifters or springs will result in changes in valve timing. Valve timing has a strong relationship to performance and emissions because the valves may open or close at the wrong time (Ref. 3).

The valve lifter transmits the action of the cam to the valve. Lifters may be directly connected to the valve stem or may act on push rods which, in turn, act to open the valve. The lifters may be either simple mechanical rods or the more complex hydraulic lifters. Mechanical lifters must be adjusted so that the correct gap (lash) in a cold engine exists between the valve stem and valve lifter. The gap allows for thermal expansion of the valve. Hydraulic lifters are used on most engines to avoid valve lash adjustments and to provide quieter lifter operation (Ref. 3).

3.6.1.2 Cams

The cam lifts the valve at the correct time to obtain the most efficient filling and emptying of the cylinder. The operation of the valves is controlled by precision-machined cams. The cams are hardened to minimize wear. However, over a long period of operation, or in the case of improper operation or fabrication, the shape of the cam will change. Wear usually occurs on the highest point of the cam decreasing the lift of the valve. This results in a smaller opening and reduced breathing of the engine. This does not significantly effect emissions, but does reduce engine power. Wear can also occur on the sides of the cam, particularly with strong springs or hydraulic lifters. In this case, the valve timing will change which can affect emissions (Ref. 3).

3.6.1.3 Guides

Valve guides are pressed into the head of the block and serve to correctly align the valve with its seat in the cylinder. Similar guides are provided for push rods if they are used. The guides are lubricated by oil running down the valve stem. As the guides and valve stem wear, more oil can flow down the stem and into the manifold or into the cylinder. This can increase smoke and HC/CO emissions (Ref. 3).

3.6.1.4 Seals

Seals are installed to prevent leakage of lubricating oil past the valve guides and into the manifold or cylinder. The seals are subject to wear and deterioration and will cause increased CO and smoke emissions if defective due to incomplete combustion of the heavy lubricating oil (Ref. 3).

3.6.1.5 Valves

Intake valves are not subject to the wear and deterioration typical of exhaust valves because they operate at low temperatures. Exhaust valves, however, are subject to high temperature, vibration, and impact stress. The valve and its seat in the cylinder must make a tight seal at the correct time to ensure that the combustion in the cylinder can be utilized efficiently without excessive emissions. Valve leaks can be caused by improper alignment of the valve train, by erosion or wear of the valve and seat, or by deposits which prevent a positive seal. Under these conditions, exhaust gases will escape from the cylinder before combustion is complete causing generally higher HC, CO, and smoke, but lower NO_x emissions (Ref. 3).

3.6.2 Piston Rings

Piston rings consist of oil control rings and compression rings. The oil control ring is the lowest on the piston and is designed to minimize movement of oil from the crankcase into the cylinder where it would burn, resulting in excessive CO, HC, and smoke emissions. The compression rings (two or more) are located near the top of the piston and are designed to seal the combustion gases in the cylinder. Leakage past the compression rings is called blowby which occurs during the compression stroke and initial phase of the expansion stroke. Blowby is captured by the PCV system and returned to the intake manifold for subsequent combustion. Excessive blowby has the effect of enrichening the mixture particularly at idle and, therefore, increasing CO emissions (Ref. 2 and 3).

3.6.3 Pistons

The piston is related to emissions because the design of the piston surface is peculiar to the specific engine design. Some pistons are manufactured with special depressions to permit localization of the flame front. The surface is subject to pitting or deposits which affect the ignition and quenching properties of the combustion chamber. As OEM parts, the pistons are not significantly related to emissions because the rate of wear and deposition is so small during the design life (Ref. 3). As after-market components, however, there is a possibility of changing cylinder geometry by using nonstandard replacement pistons. This may affect HC and NO_x emissions due to changes in compression ratio and surface to volume ratios (Ref. 2).

3.6.4 Gaskets

Gaskets are used to provide positive seals between the sections of the engine. Defective engine gaskets create water or oil leaks inside the engine block which affect the combustion process (Ref. 3). Gaskets should not fail during the certification period unless the engine has been improperly fabricated or operated.

3.6.5 Camshafts

Camshafts and their drive mechanisims are emissions-related because of their effect on valve operation. Defects are generally associated with the belt or chain drive mechanism of overhead camshafts. This wear causes valve timing to change or become erratic. However, these problems develop over long periods of operation and should not affect emissions during the certification period (Ref. 3).

3.7 EMISSION CONTROL SYSTEMS

A large number of systems and components have been developed by engine and vehicle manufacturers specifically to control emissions. Defects in these systems will usually result in increased emissions of at least one pollutant. Some systems are used on most engines. Others maybe used on only a few engines of a single manufacturer. Separate paragraphs are devoted to the following systems:

- Crankcase ventilation (PCV)
- Evaporative emissions (EVAP)
- Air injection (AIR)
- Exhaust gas recirculation (EGR)
- Transmission-controlled spark (TCS)
- Speed-controlled spark (SCS)
- Orifice spark advance control (OSAC)
- Electronic spark control (ESC)
- Catalytic reactor (CAT)

In addition, several individual components have been developed and are discussed separately under Miscellaneous Emissions-Related Parts:

- Heat riser
- Electric assist choke

- Staged choke pulldown
- Decel valve
- Distributor vacuum deceleration valve
- Thermal vacuum valves
- Distributor starting solenoid

3.7.1 Positive Crankcase Ventilation (PCV) Systems

The first emission control system used on vehicles was the positive crankcase ventilation system. The PCV system provides a controlled flow of fresh air through the engine crankcase. The closed type of PCV system, used on 1968 and later vehicles prevents escape of blowby gases into the atmosphere. Individual system designs vary by manufacturer but generally include the following components:

- PCV valve
- PCV hoses
- PCV fresh air filter
- PCV oil separator

3.7.1.1 PCV Valve

The purpose of the PCV valve is to reduce the flow through the system during idle and deceleration when manifold vacuum is high. Without the PCV valve, the flow through the PCV system would be very high due to the vacuum. At the same time, the carburetor airflow is low. The extra airflow through the PCV system would cause lean misfire and possibly stalling of the engine (Ref. 3).

The PCV valve is a spring-loaded plunger which is open at low vacuum; i.e., open throttle. This enables relatively high flow rate through the valve during times of high speed operation. Under high vacuum, the valve is closed against the spring leaving small orifices for the gases to flow through. This maintains PCV flow in proportion to the low carburetor airflow in spite of the high manifold vacuum. Flow through the PCV valve can be restricted by clogging from particles and oil droplets drawn out of the engine crankcase. This results in some fuel enrichment and increased HC and CO emissions because less air is drawn into the engine and can result in backflowing of crankcase gases, under pressure, to the air cleaner (Ref. 3 and 27). This can also result in flow restriction of the air cleaner.

3.7.1.2 PCV System Hoses

The PCV valve is connected to the manifold vacuum port by reinforced rubber vacuum hoses. Similar hoses connect the air cleaner to the crankcase air inlet which may be in the oil filler cap or the valve covers. The PCV system may also be interconnected with the EGR or EVAP systems (Ref. 3).

Breaks or loose connections in the PCV hoses can result in loss of blowby fumes, primarily unburned fuel, into the atmosphere. They may also create a manifold vacuum leak if the break occurs in the hose connecting the manifold to the PCV valve.

3.7.1.3 PCV Fresh Air Filter

An auxiliary filter is usually supplied to filter airborne particulates from the crankcase ventilation air. Clogging of the filter will reduce ventilation flow. If oil is clogging the filter, it may indicate that the PCV valve is also clogged. Reduced flow through the filter will result in enrichening of the air-fuel ratio and higher CO emissions (Ref. 3).

3.7.1.4 PCV Oil Separator

An oil separator is supplied with some engines to help remove entrained oil droplets from the crankcase vapors. However, most of these are integral parts of the engine block or valve covers and cannot be serviced. Failure of an oil separator results in more oil passing through the PCV system which encourages early failures due to clogging (Ref. 3).

3.7.2 Evaporative Emission Control (EVAP) System

Evaporative emission control systems prevent escape of gasoline vapors from the fuel tank and carburetor. All manufacturers use similar systems, although the specific components and flowpaths may differ. The EVAP system generally consists of the following components:

- Activated carbon canister
- Vacuum, vapor, and gasoline hoses and line
- Fresh air filter
- Vapor-liquid separator
- Vapor control valves

3.7.2.1 Activated Carbon Canister

Most systems employ an activated carbon canister to store the fuel vapors. During engine shutdown, the fuel vapors are routed to the activated carbon canister by the slight pressure of the expanding vapors. The activated carbon in the canister absorbs and holds the vapors allowing vapor-free air to escape to the atmosphere. When the engine is started, manifold vacuum draws the absorbed vapors into the engine. The carbon canister is very durable even if occasionally saturated. Failure of the canister causes excessive evaporative HC emissions (Ref. 3 and 27).

3.7.2.2 EVAP System Hoses and Lines

The evaporative system involves several vapor, vacuum, and liquid lines, and their associated connectors and fittings. A break in any line will release fuel vapor to the atmosphere. In addition, a break in the vacuum line between the carburetor and canister may cause lean misfire due to the vacuum leak.

3.7.2.3 EVAP System Fresh Air Filter

The canister incorporates a filter for removal of large particulates and droplets from the purge air. This prevents clogging of the carbon which could reduce its efficiency for storage and purging. A restricted EVAP system filter may increase evaporative HC emissions because the canister is not effectively purged between soaks (Ref. 3 and 27).

3.7.2.4 EVAP Vapor/Liquid Separator

The liquid fuel is separated from the fuel vapor in or immediately adjacent to the fuel tank by a separator which directs the fuel vapors to the canister. The separator is usually of a simple standpipe design and, therefore, is durable and reliable. To prevent overfilling of the fuel fuel tank and, consequently, flooding of the separator, an expansion void is frequently incorporated in the fuel tank (Ref. 27).

3.7.2.5 EVAP Vapor Control Valves

Several vapor control valves may be used in the EVAP system. These include check valves and vacuum valves which regulate the direction and flow rate of fuel vapors into and out of the canister. These valves are frequently an integral part of the activated carbon canister or fuel tank. However, where the valve is a separate replaceable component, it is included in this category. The vacuum valves control the purge air flow rate in the same manner as the PCV valve regulates crankcase ventilation air. At idle, low flow is allowed through small orifices. However, at higher speeds when higher flows from the EVAP system can be tolerated, the purge valve opens under spring action allowing flow through larger orifices (Ref. 27).

3.7.2.6 Fuel Tank

The fuel tanks are integral parts of the EVAP system and may include vapor separators, fuel return lines, and expansion chambers. The fuel tanks also incorporate a sealed gas cap which permits make-up air to enter the tank but prevents fuel vapors from escaping except to release dangerously high pressure. Failure of the gas cap will release fuel vapors to the atmosphere (Ref. 3 and 27).

3.7.3 Air Injection (AI) System

Air injection systems have been used for emissions control since 1966 with only slight modification. Air injection systems use auxiliary air injection adjacent to the exhaust valves to oxidize HC and CO emissions leaving the cylinder. Air injection systems are effective in reducing emissions because of incomplete combustion in the quench zones, scavenging of unburned carbureted mixture during intake and exhaust valve overlap, and excess emissions due to carburetor or ignition system defects. Some catalyst-equipped vehicles utilize air injection at the catalyst rather than in the exhaust manifold. The details of the systems vary somewhat, although similar components are generally used.

Air injection systems consist of the following components:

- Distribution manifold and nozzles
- Hoses
- Inlet air filter
- Check valves
- Bypass or diverter valves
- Gulp valves
- Pump, belt, and seals

3.7.3.1 Manifold and Nozzles

The manifold and nozzles are fabricated in or on the engine. They should be good for the life of the engine and there is no significant emissions failure mode (Ref. 3).

3.7.3.2 Hoses

Reinforced vacuum hoses are used to connect the air injection pump to the air distribution manifold. The hoses are subject to thermal and mechanical deterioration. However, unless completely broken, there should not be a significant reduction in air delivery. The air injection hoses should not fail within the certification period, but if they do, will result in no air delivery (Ref. 3 and 27).

3.7.3.3 Inlet Filter

A particulate filter is installed in the intake to the pump. This filter prevents the introduction of coarse particulates into the pump which could damage the pump and clog air control valves or injector tips. The air filter is usually integral to the pump and is designed to last the life of the pump under normal use (Ref. 3).

3.7.3.4 Check Valves

All AI systems employ check valves to prevent backflow of hot exhaust gases in the event of high pressure in the exhaust manifold or failure of the air pump or hoses. The check valves are generally good for the life of the engine and help prevent damage to the pump or hoses if backfiring or detonation occurs in the manifold (Ref. 3).

3.7.3.5 Bypass or Diverter Valves

Several different types of bypass or diverter valves are used to prevent backfiring, and in catalyst-equipped vehicles, excessive temperature due to certain engine operating conditions. The bypass or diverter valves dump air into the atmosphere during deceleration (high vacuum) and high speed (high air supply pressure). The valves are generally operated by manifold vacuum. Catalyst-equipped vehicles may also have thermally controlled switches which activate the diverter valve to prevent high temperatures in the catalyst during deceleration, cold start, or engine malfunction. The diverter valve is subject to diaphragm deterioration which can prevent the valves from operating during deceleration (Ref. 3 and 27).

3.7.3.6 Gulp Valves

Gulp valves were incorporated on early air injection systems but generally have been eliminated in favor of the diverter or bypass values presently used. Some foreign manufacturers use a form of gulp valve for control of deceleration hydrocarbon emissions. These valves admit additional air to the carburetor or intake manifold to prevent excessive fuel enrichment during deceleration. Gulp and mixture control valves are used to regulate airflow into the intake manifold. Throttle-poppet valves regulate airflow past the throttle. All three valve types are spring-controlled vacuum valves which open under conditions of high manifold vacuum. Failure of the valve will result in mixture enrichment during decelerations and higher HC and CO emissions (Ref. 3 and 27).

3.7.3.7 Pump, Belts and Seals

The air injection pump and associated belts, pulleys, and seals provide the air supply for the AI system. The pump is highly reliable and should operate well beyond the certification period. However, improper belt tension adjustment can cause slippage or excessive wear of the belt. Excessive tension can also cause accelerated wear of the pump pulley bearings. Pumps are generally not serviceable and are replaced when defective. If defective, the AI system will be disabled causing higher HC and CO emissions (Ref. 3 and 27).

3.7.4 Exhaust Gas Recirculation (EGR) Systems

Control of NO_x emissions is partly accomplished by EGR, in which a portion of the inert exhaust gases are metered back into the intake manifold. The exhaust gases reduce combustion temperatures and prevent formation of NO_x. Two EGR concepts have been employed: passive bleed jets between the exhaust and intake manifolds; and actively modulated EGR valves modulated by temperature, vacuum and/or exhaust pressure. As emission standards have become more stringent, the complexity of EGR systems have increased. EGR systems can be composed of the following components:

- EGR valve or orifice
- Hoses

- Temperature-controlled vacuum valves
- Solenoid-controlled vacuum valves
- Temperature switch
- Speed/transmission switch
- Time delay control
- Vacuum amplifier
- Vacuum-reducing valve
- Carburetor spacer
- Back pressure sensor
- Check valves

3.7.4.1 EGR Valve or Orifice

The fixed orifice or floor jet type EGR valve was used only in a few engine families. Therefore, these systems will not be discussed other than to say that plugging of the orifices was common. The vacuum-modulated EGR valve, now used exclusively, consists of a vacuum, diaphragm-operated valve. Vacuum signals, modulated by load and sometimes thermal conditions, are used to open the valve in proportion to throttle opening. The valve is closed by return springs. The EGR valve is subject to thermal and mechanical deterioration and clogging by particulates, condensed water, and oil in the exhaust gases. Failure of the EGR valve increases NO_x significantly (Ref. 2, 3, 27 and 86).

3.7.4.2 EGR Hoses, Passages, Seals

Except for some after-market retrofit systems, all hoses or tubes carrying the exhaust gases are metalic to resist the high exhaust gas temperature. EGR vacuum control lines, however, are standard vacuum hoses. Failure of vacuum hoses or fittings can result in a vacuum leak as well as disabling the EGR system. This will increase both HC and NO_x emissions (Ref. 3 and 27).

3.7.4.3 EGR Temperature-Controlled Valves

Thermal vacuum valves are used in some applications to modulate EGR during cold temperature operation. These valves usually sense coolant temperature and shutoff vacuum signals activating EGR. This promotes more rapid warm up for control of cold start HC and CO emissions. Failure of the valve to open would increase NO_x substantially. Failure of the valve to close would slightly increase HC and CO during warm up (Ref. 3 and 27).

3.7.4.4 EGR Solenoid-Controlled Vacuum Valves

Some systems are modulated by electrically-operated solenoid valves which may be interconnected with TCS, SCS, or thermal vacuum switch systems. The solenoid vacuum valves are generally more reliable than vacuum-operated valves. The characteristic failure will prevent opening of the valve which prevents any EGR (Ref. 3 and 27).

3.7.4.5 EGR Temperature Switches

Temperature switches are used in conjunction with solenoid-controlled vacuum valves to regulate EGR during cold temperature operation. Temperature-sensing switches are very reliable and should not require servicing. Their failure will prevent any EGR (Ref. 3 and 27).

3.7.4.6 EGR Speed/Transmission Switch

Some systems modulate EGR in conjunction with transmission gear position or speed. These systems are often interconnected with timing retard systems. These switches are very reliable and should not require servicing. Their failure will prevent EGR at any speed (Ref. 3 and 27).

3.7.4.7 EGR Time Delay

Some applications use electrical delays to prevent EGR immediately following start-up to ensure stable idling These systems employ electrical timers which activate a vacuum solenoid valve to prevent EGR even though the coolant temperature is high enough to permit EGR. Failure of the time delay mechanism may prevent any EGR (Ref. 3 and 27). Since this is a more severe failure condition than providing EGR at all times, it has been selected as the mode of failure for this study.

3.7.4.8 EGR Vacuum Amplifier

Some systems employ a ported vacuum signal to control EGR in proportion to the throttle opening. The ported vacuum signal, however, may not be strong enough to actuate the EGR valve. Therefore, manifold vacuum is used to operate the valve and is modulated by the ported vacuum in a manner similar to electric relays. The EGR vacuum amplifier will create a large vacuum leak if defective. This can affect performance and increase both HC (misfire) and NO_x (no EGR) (Ref. 2, 3 and 27).

3.7.4.9 EGR Vacuum-Reducing Valve

Some applications use a vacuum-reducing valve to reduce the manifold vacuum under certain conditions. This valve consists of, or is used in conjunction with, a solenoid or thermal vacuum valve which opens an air bleed to release or reduce the vacuum signal. Vacuum-reducing valves are used to modulate EGR under certain throttle or temperature conditions (Ref. 3 and 27).

3.7.4.10 EGR Carburetor Spacer

The carburetor spacer contains passages for introducing the recirculated exhaust gases into the carbureted mixture. The spacer is not subject to significant deterioration, but the passages can become clogged with exhaust gas particles. The failure of the spacer would increase NO_x because EGR flow would be reduced (Ref. 3 and 27).

3.7.4.11 EGR Back Pressure Sensor

Some California-configuration vehicles employ a back pressure sensor to more accurately proportion the EGR to load and throttle opening. The back pressure sensor responds to pressure in the exhaust manifold which increases with throttle opening. The pressure moves a diaphragm against a spring to close an air bleed in the vacuum line of the EGR valve. This increases the vacuum signal and results in higher EGR. This valve can become clogged resulting in reduced EGR at all times and, consequently, higher NO_x (Ref. 3 and 27).

3.7.4.12 EGR Check Valves

Some applications use a check valve to hold the highest ported vacuum obtained during acceleration to ensure high EGR and reduced NO_x. These valves are reliable and not subject to severe operating conditions. Therefore, they should operate satisfactorily well beyond the certification period. Their failure will result in normal vacuum variations and slight reduction in EGR (Ref. 3 and 27).

3.7.5 Transmission-Controlled Spark (TCS)

Most manufacturers use transmission-controlled spark systems to reduce timing advance during certain operating conditions. Acceleration and heavy load operation are typically performed in low gears. Therefore, TCS systems are designed to provide retarded timing except in the highest gear. Both manual and automatic transmissions may use speed sensors instead of transmission gear sensors. TCS systems incorporate numerous protective and override systems and are frequently interconnected with EGR systems.

TCS systems consist of the various combinations of the following components:

- Solenoid vacuum valve
- Vacuum lines and hoses
- Time delay control
- CEC valves
- Thermal vacuum valves
- Transmission switch
- Reversing relay

3.7.5.1 TCS Solenoid Vacuum Valve

An electrically-operated solenoid valve controls the amount of vacuum provided to the distributor vacuum advance diaphragm. In some configurations, the valve selects either ported or manifold vacuum sources. In others, it provides full manifold vacuum or vents vacuum to the atmosphere which provides no vacuum advance at all. Depending on the configuration, the valve could fail providing either no or full advance at all times. For NO_x, full advance at all times is the most critical failure mode (Ref. 3 and 27).

3.7.5.2 Vacuum Lines and Hoses

The distributor advance unit is connected to the manifold vacuum by a very complex routing of vacuum lines. Any leak in the lines will result in reduced vacuum advance which will reduce NO_x and may create vacuum leaks resulting in higher HC emissions due to lean misfire (Ref. 3 and 27).

3.7.5.3 TCS Time Delay Control

Some systems incorporate time delays to permit stable idling before the TCS system is activated. They operate in the same manner described above for EGR time delay controls and will prevent TCS operation if defective (Ref. 3 and 27).

3.7.5.4 TCS CEC Solenoid

Some vehicles use a CEC solenoid in the TCS system. The CEC solenoid incorporates the functions of a throttle positioner and a vacuum solenoid. The CEC solenoid simultaneously regulates distributor vacuum advance and throttle closure. The CEC plunger must be properly adjusted to correctly regulate deceleration from high speed to prevent excess HC emissions. Once adjusted, however, the valve and plunger should not require service during the certification period. Failure of the CEC solenoid will result in no deceleration throttle control and no vacuum advance. This will cause reduced NO_x but higher HC and CO (Ref. 3 and 27).

3.7.5.5 TCS Thermal Vacuum Valve

The TCS system may be modulated by several thermal vacuum valves which sense coolant temperature. The vacuum valves are usually used to disable TCS vacuum retard when the coolant temperature is less than or greater than specified limits. Thermal vacuum valves (TVV) are also called ported vacuum switches (PVS), coolant temperatures overrides (CTO) and thermal ignition control (TIC) valves. Thermal vacuum valves come in numerous configurations such as two, three, four and five port valves and various temperature ranges

(Ref. 3 and 27). Thermal vacuum valves are durable and not exposed to severe environments. They should, therefore, operate beyond the certification period. If they fail, they will most likely fail in the normal operating position providing normal vacuum advance.

3.7.5.6 TCS Transmission Switch

The TCS solenoid vacuum valve is actuated by a transmission switch which senses gear selection. It is identical in nature and operation to the EGR transmission switch described above (Ref. 3 and 27).

3.7.5.7 TCS Reversing Relay

A relay is provided in a few applications which defeats the vacuum retard function of the TCS system. One configuration employs a latching relay which prevents TCS as long as carburetor inlet air temperature is low. Once the air temperature becomes higher, the TCS function is restored. This system could prevent any vacuum retard, if defective, resulting in increased NO_x emissions (Ref. 3 and 27).

3.7.5.8 TCS Temperature-Controlled Switch

In some applications, the temperature override function of the thermal vacuum valve is performed by an electrical switch wired in series between the speed switch and solenoid vacuum valve. This switch functions in the same manner as described for EGR temperature-controlled switches (Ref. 3 and 27).

3.7.6 Speed-Controlled Spark (SCS) System

Some applications utilize speed-controlled spark, particularly on automatic transmission vehicles. The SCS system is distinguished from TCS primarily because road speed is sensed in terms of mph rather than transmission gear selection. The other components are similar and, in many cases, identical to TCS systems and will not be discussed further (Ref. 3 and 27).

3.7.7 Orifice Spark Advance Control (OSAC)

The orifice spark control system is a method of modulating vacuum advance. The system is used in conjunction with EGR or TCS for control of NO_x. The system incorporates override systems during certain engine operating conditions. The OSAC system incorporates the following components:

- OSAC orifice valve
- OSAC vacuum hoses
- OSAC vacuum control valves
- OSAC temperature sensor

3.7.7.1 OSAC Orifice Valve

The OSAC orifice valve is similar in function to the spark delay valve. The valve delays increase of ported vacuum to the distributor vacuum advance unit as the throttle is opened. During throttle closure, the reduction of ported vacuum is instantaneous. This effectively retards timing during loaded accelerations. The OSAC valve consists of an integral orifice and check valve which restricts flow in one direction but not the other. The OSAC valve is typically located on the air cleaner housing where it senses air temperature in the air cleaner. Failure of the valve enables normal vacuum signals to reach the distributor and increase NO_x (Ref. 3 and 27).

3.7.7.2 OSAC Vacuum Hoses

Vacuum hoses are routed between the OSAC valve, the distributor vacuum advance unit and the thermal control valves. The hoses must be leak tight to ensure correct operation of the OSAC system. Vacuum hose failure between the OSAC valve and thermal vacuum valve will result in no vacuum advance unless overheating occurs; then full vacuum advance. Vacuum hose failure between the manifold vacuum source and distributor vacuum advance unit may result in no vacuum advance and/or intake manifold vacuum leak depending on temperature. Emissions of NO_x and possibly HC will increase (Ref. 3).

3.7.7.3 OSAC Vacuum Control Valve

The OSAC vacuum control valve, also called the thermal ignition control (TIC) or temperature operated bypass (TOB) valve, is used on some vehicles to apply full manifold vacuum to the distributor advance unit if the engine overheats. This valve is termed a coolant temperature override valve or thermal vacuum valve by other manufacturers when associated with distributor vacuum advance modulation. The higher manifold vacuum causes higher engine rpm and improved cooling. The valve is located in the cooling jacket or the radiator, depending on application. Failure of the valve either provides delayed ported or full vacuum advance at all times (Ref. 3 and 27).

3.7.7.4 OSAC Temperature Sensor

Some OSAC systems were modulated by air temperature using a temperature sensor integral to the OSAC orifice valve body. This sensor defeats the OSAC valve during cold ambient temperatures to improve driveability. The temperature sensor bypasses the ported vacuum around the orifice in the OSAC valve (Ref. 3 and 27).

3.7.8 Electronic Spark Control (ESC) System

The electronic spark control system was used in some applications to modulate vacuum advance during various operating conditions. The system regulated vacuum advance using electrical sensors and solenoids rather than thermal vacuum valves. The ESC system is not related to electronic ignition systems. The ESC system is composed of the following components:

- Electronic module
- Vacuum hoses/wires
- Solenoid vacuum valves
- Temperature-sensing switches
- Speed-sensing switches

3.7.8.1 Electronic Module

The distributor vacuum is modulated by a solenoid which is controlled by the electronic module. The electronic module compares ambient temperature and vehicle speed to specified values. Above 65°F, the module will disable the vacuum advance at low speed and enable it at high speed (23 to 35 mph depending on application). Below 49°F, the module will enable vacuum advance at all speeds. The module consists of solid-state circuits and is highly reliable. Failure of the module will result in normal vacuum advance at all times (Ref. 3 and 27).

3.7.8.2 ESC Hoses

The solenoid vacuum valve is placed between the manifold vacuum source and distributor advance unit.

Failure of the hoses will result in loss of advance to the distributor and may create a vacuum leak causing high HC (Ref. 27).

3.7.8.3 ESC Solenoid Vacuum Valve

The ESC solenoid vacuum valve, also called a distributor modulator valve (DMV), controls the vacuum to the distributor. Failure of the solenoid will result in normal vacuum advance at all times and higher NO_x emissions (Ref. 27).

3.7.8.4 ESC Temperature-Sensing Switch

The ambient air switch overrides the speed modulation of the distributor. Failure of the switch disables the ESC system resulting in normal operation of the ~~ESC system~~ (Ref. 27). vacuum advance at all times.

3.7.8.5 ESC Speed-Sensing Switch

The speed sensor is driven by the speedometer cable. It is a DC tachometer generator and is highly reliable. Failure of the sensor would result in no vacuum advance at anytime. This reduces NO_x but also can increase emissions HC and CO slightly (Ref. 27).

3.7.9 Catalytic Reactor

Most 1975 and 1976 model-year vehicles are equipped with catalytic reactors for control of HC and CO emissions and to permit some reduction of NO_x emissions by enrichment of carburetor adjustments. Catalysts consist of the following components:

- Reactor body
- Active media

In addition to the catalyst itself, some systems employ catalyst protection devices which modulate air injection. The air injection systems were discussed in paragraph 3.7.3.

3.7.9.1 Reactor Body

The outer catalyst body consists of heat shields to protect the underside of the vehicle from fire. The catalyst shell itself is heat resistent stainless steel and incorporates flow diffusers to direct and distribute the exhaust gas throughout the catalyst. The structural body is not subject to deterioration but can be damaged by collision or impact. Failure of the catalyst body will increase HC and CO emissions slightly (Ref. 27, 35, 47, 59, 72, 81 and 82).

3.7.9.2 CAT Active Media

Catalytic active media is usually platinum but may also include some palladium and rhodium. The active media is subject to deterioration by chemical bonding with poisons such as lead and phosphorus. The active media may also be damaged by physical coating by particulate material (Ref. 72 73, 76, 81 and 82).

Catalysts are either monolithic or pelleted. In both cases, the active media is distributed over and supported by an inert silicate which provides large surface area. Thermal cycling and stress tends to cause the pore size to increase reducing the surface area. This helps to explain the gradual loss of catalyst efficiency typical of high mileage accumulation. Without ignition or carburetion failure, the catalyst should last the design life of the vehicle. However, structural damage to the catalyst, due to high temperature, results in substantial increases in both HC and CO emissions (Ref. 7, 10, 15, 28, 29, 35, 47, 72, 73, 81 and 82).

Several catalytic systems, including dual catalysts and three-way catalysts, are under active development and precertification testing. These catalyst systems have not been included in this study. They are expected to have similar relationships to emissions as conventional oxidation catalysts.

3.7.10 Miscellaneous Emissions-Related Parts

Several components are not specifically included in any emissions control system. These parts include:

- Heat riser
- Electric assist choke
- Staged choke pulldown
- Decel valve
- Distributor deceleration valve
- Thermal vacuum valve
- Distributor vacuum valve

3.7.10.1 Heat Riser

The heat riser, also called manifold heat control, has been employed on most engines for many years to improve cold start performance and emissions and to reduce warm-up time. The heat riser is a thermostatically-controlled valve which directs exhaust gases against the intake manifold when the engine is cold. When the engine is hot, the valve closes to direct the exhaust gases into the exhaust pipe. The heat riser can stick, typically closed, so that warm-up is delayed causing increased HC and CO emissions. Some engines use vacuum-operated valves (Early Fuel Evaporation, Exhaust Heat Control) modulated by thermal vacuum switches, to activate the heat riser (Ref. 2, 3, 48 and 78).

3.7.10.2 Electric Assist Choke

Some engines use electric resistance heaters to cause more rapid choke opening. The choke thermostat operates normally. At low ambient temperatures, the heater is deactivated by a bimetal thermostat. At higher ambient temperatures (60°F), the heater is activated providing additional heat to the choke thermostat. The more rapid choke opening reduces HC and CO emissions. Failure of the system would cause higher HC and CO cold start emissions (Ref. 3 and 27).

3.7.10.3 Staged Choke Pulldown

The staged choke pulldown used on some models provides more accurate choke modulation as a function of temperature. The pulldown consists of a temperature-controlled vacuum valve which pulls the choke open more rapidly than normal. The rate of opening is controlled by fluid flowing through an orifice. This permits a vacuum diaphragm connected to the choke plate to move. At temperatures above 60°F, the temperature valve opens allowing vacuum to pull the choke nearly open soon after engine start. At colder temperatures, normal choke opening is provided. Failure of the valve will usually result in normal choke action and slightly higher CO and HC emissions (Ref. 3 and 27).

3.7.10.4 Decel Valve

The decel valve is used to provides additional carbureted mixture during periods of high intake manifold vacuum, (i.e., decelerations). The valve is a diaphragm which opens under vacuum to admit a mixture of fuel and air to the intake manifold. The added fuel maintains stable combustion and engine operation, thereby, reducing HC and CO emissions. Defects in the valve will usually cause increased emissions either due to insufficient or excessive additional mixture (Ref. 2, 3 and 27).

3.7.10.5 Distributor Vacuum Deceleration Valve

The distributor vacuum deceleration valve (DVDV) also called deceleration or vacuum advance control valve is used to provide maximum vacuum advance of ignition timing during deceleration (high manifold vacuum). At idle and normal part throttle operation (low vacuum), the distributor advance is connected to the carburetor spark port for normal advance modulation. The DVDV consists of a spring-loaded vacuum diaphragm which responds to manifold vacuum to control the vacuum source provided to the distributor. Failure of the valve diaphragm will result in manifold vacuum applied to the distributor due to leakage past the diaphragm. This will cause increased NO_x emissions (Ref. 2, 3 and 27).

3.7.10.6 Distributor Starting Solenoid

The distributor starting solenoid is a mechanical advance mechanism to provide additional spark advance during engine cranking. This improves engine starting while maintaining low HC and CO emissions during idle. The advance is provided by a solenoid directly connected to the vacuum advance linkage. Failure of the solenoid will result in normal advance (none) during starting, but will not increase emissions significantly unless the engine stalls after starting (Ref. 3 and 27).

3.7.10.7 Thermal Vacuum Valve

All manufacturers use thermal vacuum valves in a variety of applications. Valves which are part of major control systems were categorized under that system's description. However, some thermal vacuum valves are incorporated in special purpose systems or used only to provide hot coolant temperature override of retarded spark. These valves are included in this category (Ref. 3 and 27).

3.7.10.8 Distributor Vacuum Valve

The distributor vacuum valve is similar to the distributor vacuum deceleration valve described above, but is used to modulate part throttle advance rather than deceleration advance. The valve selects ported vacuum at open throttle acceleration but switches to the EGR port at higher vacuum. This change in vacuum source at part throttle cruise improves driveability of vehicles. Failure of the distributor vacuum valve would result in slightly increased emissions of NO_x and ported vacuum at all times (Ref. 3 and 27).

3.8 EMISSIONS-RELATED PARTS LIST

The system descriptions, probable defect conditions, and the effect of defects on emissions discussed above were used to identify emissions-related components. Although nearly all components can have some effect on emissions, not all can cause an emissions failure. An emission failure depends on both the increase from baseline and the relationship of the baseline to the applicable standard. Therefore, all components which appeared to have more than a negligible effect on one or more pollutant were included in the emissions-related parts list presented in Table 3-1.

Table 3-1. EMISSIONS-RELATED PARTS LIST
ORIGINAL EQUIPMENT PARTS

PART OR COMPONENT	RELATED EMISSION			
	HC	CO	NO_x	Smoke
Carburetor System				
Idle Stop Solenoid	x	x		
Throttle Dashpot	x	x		
Throttle Positioner	x	x		
Metering Jets	x	x		
Metering Rods	x	x		
Vacuum Break Valves	x	x		
Choke Mechanism	x	x		
Accelerator Pumps	x	x		
Power Valves	x	x		
Gaskets	x	x		
Float and Valve	x	x		
Idle Adjustment	x	x		
Heat Riser	x	x		
Idle Enrichment System	x	x		
Electric Assisted Choke	x	x		
Staged Choke Pulldown	x	x		
Fuel Filter	x	x		
Ignition System				
Points	x	x		
Condenser/Capacitor	x	x		
Distributor Cap	x	x		
Distributor Rotor	x	x		
Mechanical Advance Mechanism		x		
Vacuum Advance Mechanism		x		
Distributor Drive Mechanism	x	x		
Magnetic or Optical Triggers	x	x		
Spark Plugs	x	x		
Ignition Wires	x	x		
Coil - Inductive	x	x		
Ballast Resistor	x	x		
Ignition Timing Adjustment	x		x	
Spark Delay Valve	x		x	
Air Induction System				
Thermostatically-Controlled Air Inlet	x	x		
Vacuum Motor and Hoses	x	x		
Air Cleaner Element	x	x		
Turbochargers				x

Table 3-1. EMISSIONS-RELATED PARTS LIST
ORIGINAL EQUIPMENT PARTS (Continued)

PART OR COMPONENT	RELATED EMISSION			
	HC	CO	NO$_x$	Smoke
Fuel Injection System				
Accumlator				x
Fuel Pressure Sensors/Regulators	x	x		x
Throttle Linkage and Valve	x	x		x
Injection Valves				x
Air Sensors/Switches	x	x		
Temperature Sensors/Switches	x	x		
Injectors	x	x		
Triggering Switches	x	x	x	
Starting Valve	x	x		
Idle Adjustment Screws	x	x		
Engine System				
Valve Lifters and Springs	x	x		x
Cams	x	x		x
Valves, Guides and Seats	x	x		x
Seats	x	x		x
Rings	x	x		x
Gaskets	x	x		x
Camshafts	x	x		x
Emission Control System				
PCV Valve	x	x		
PCV Hoses	x	x		
PCV Fresh Air Filter	x	x		
AI Distribution Manifold	x	x		
AI Hoses	x	x		
AI Inlet Filter	x	x		
AI Check Valves	x	x		
AI Bypass/Diverter Valves	x	x		
AI Gulp Valves	x	x		
AI Pump	x	x		
EVAP Canister Body and Carbon Media	x			
EVAP Hoses	x	x		
EVAP Fresh Air Filter	x			
EVAP Vapor/Liquid Separator	x			
EVAP System Vapor Control Valves	x			
EVAP Fuel Tank Cap	x			
EGR Valves or Orifices			x	
EGR Hoses, Gaskets, Seals	x		x	
EGR Temperature-Controlled Valve			x	
EGR Solenoid-Controlled Valve			x	

Table 3-1. EMISSIONS-RELATED PARTS LIST ORIGINAL EQUIPMENT PARTS (Continued)

PART OR COMPONENT	RELATED EMISSION			
	HC	CO	NO_x	Smoke
Emission Control System (Cont'd)				
EGR Temperature Switch			x	
EGR Speed/Transmission Switch			x	
EGR Time Delay Control			x	
EGR Vacuum Amplifier	x		x	
EGR Vacuum Reducing Valve			x	
EGR Carburetor Spacer			x	
EGR Back Pressure Sensor			x	
EGR Check Valve			x	
TCS Vacuum Solenoid	x		x	
TCS Vacuum Lines and Hoses	x	x	x	
TCS Time Delay Control	x		x	
TCS CEC Valve	x	x		
TCS Temperature Control Valve	x		x	
TCS Transmission Switch	x		x	
TCS Reversing Relay	x		x	
SCS Vacuum Solenoid	x		x	
SCS Vacuum Lines	x	x		
SCS Time Delay Control	x		x	
SCS Speed Sensing Switch	x		x	
SCS Temperature-Controlled Valve	x		x	
OSAC Vacuum Orifice Valve	x		x	
OSAC Vacuum Hoses	x	x		
OSAC Thermal Valve	x		x	
OSAC Vacuum Bypass Valve	x		x	
OSAC Temperature Sensor	x		x	
ESC Electronic Module	x		x	
ESC Hoses	x	x		
ESC Vacuum Valves	x		x	
ESC Temperature Sensing	x		x	
ESC Speed Sensing Switch	x		x	
CAT Body	x	x		
CAT Active Media	x	x		
Heat Riser	x	x		
Decel Valve	x	x		
Distributor Vacuum Deceleration Valve	x		x	
Distributor Starting Solenoid	x	x		
Thermal Vacuum Valve	x		x	

Section 4

EMISSION-CRITICAL COMPONENTS

The emissions-related components described in Section 3 were ranked in the order of their criticality in causing excessive emissions. The ranking was based on the following four factors: increase in emissions, component usage, probability of failure and probability of repair. This section describes the model used to rank the components, the values assigned to the input parameters of the model, and the resulting rank-ordered lists of emission-critical components.

4.1 CRITICALITY INDEX MODEL

A computer model was developed to select the most emission-critical components. This model calculated a criticality index for each component and then ranked the indices in descending order. Separate rank-ordered lists were prepared for each pollutant (HC, CO, NO_x, smoke) and for early model-years (1972 through 1974), late model-years (1975), and a sales weighted composite of 1972 to 1975 model-years. The general flowchart of the model is shown in Figure 4-1. Specifically, the model performed the following functions:

- Read-in data by engine family and part code.

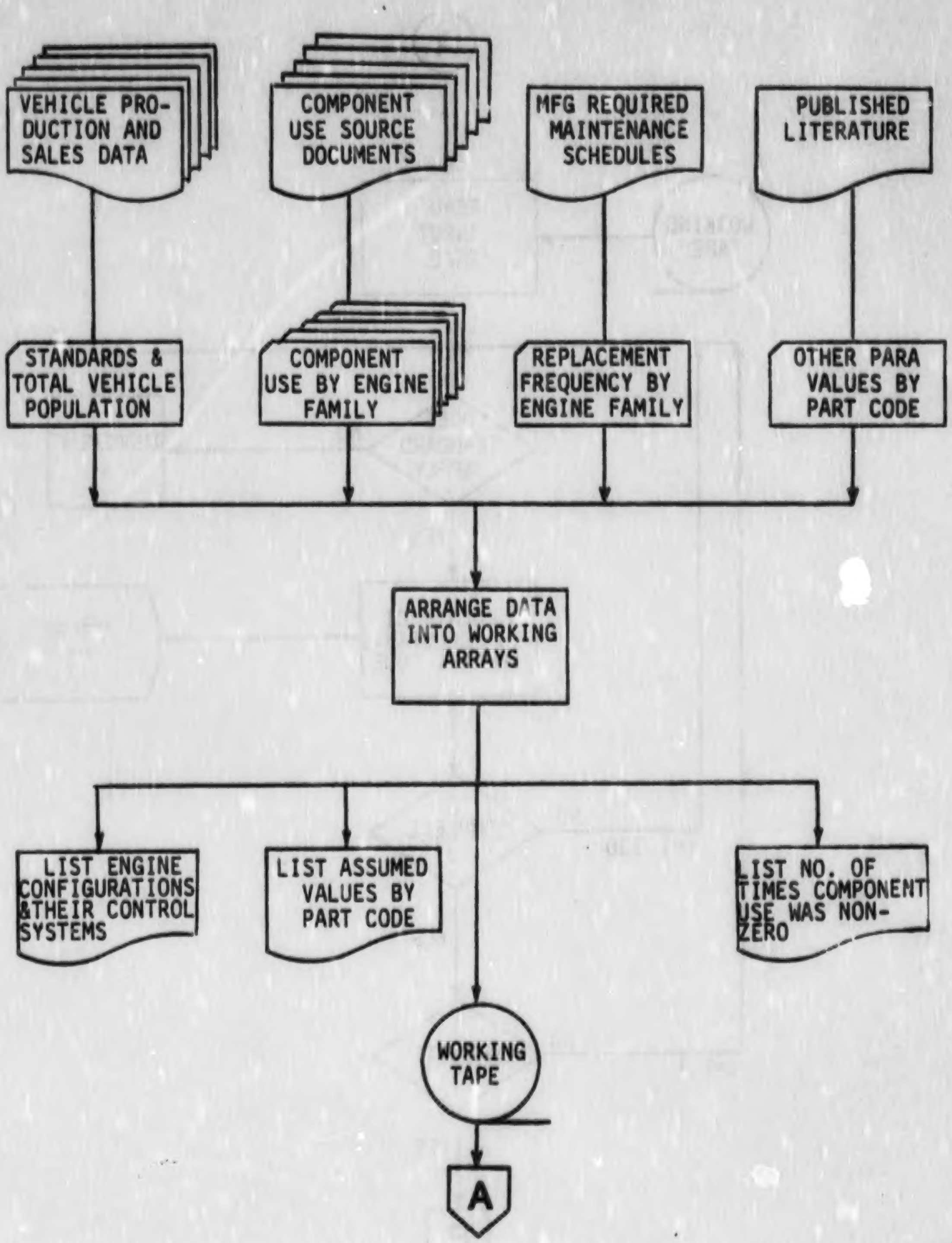

VEHICLE PRODUCTION AND SALES DATA
COMPONENT USE SOURCE DOCUMENTS
MFG REQUIRED MAINTENANCE SCHEDULES
PUBLISHED LITERATURE
STANDARDS & TOTAL VEHICLE POPULATION
COMPONENT USE BY ENGINE FAMILY
REPLACEMENT FREQUENCY BY ENGINE FAMILY
OTHER PARA VALUES BY PART CODE
ARRANGE DATA INTO WORKING ARRAYS
LIST ENGINE CONFIGURATIONS &THEIR CONTROL SYSTEMS
LIST ASSUMED VALUES BY PART CODE
LIST NO. OF TIMES COMPONENT USE WAS NON-ZERO
WORKING TAPE
A

Figure 4-1. CRITICALITY MODEL FLOWCHART

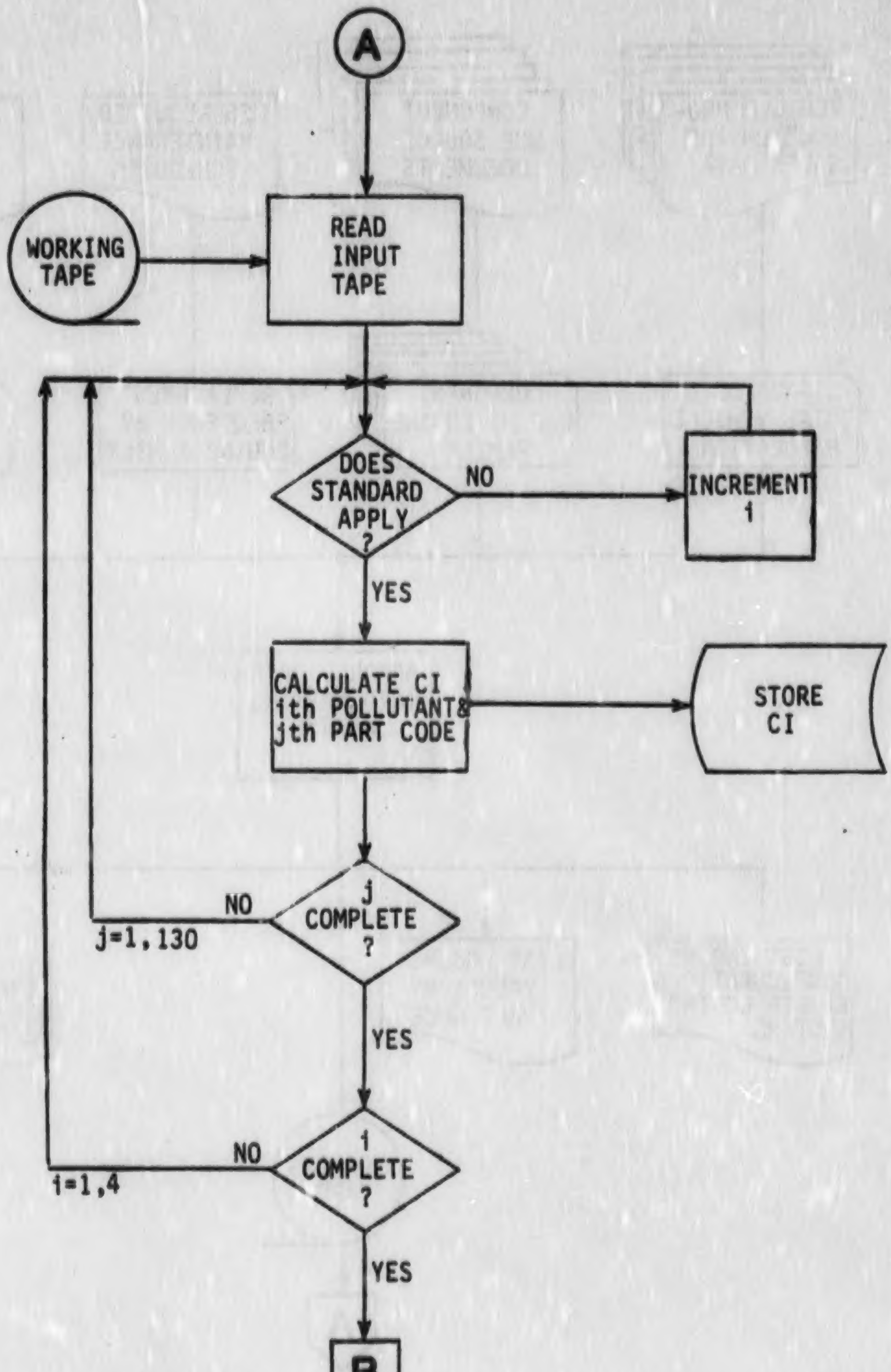

A
WORKING TAPE
READ INPUT TAPE
DOES STANDARD APPLY ?
NO
INCREMENT i
YES
CALCULATE CI ith POLLUTANT& jth PART CODE
STORE CI
NO
j=1, 130
j COMPLETE ?
YES
NO
i=1,4
i COMPLETE ?
YES
B

Figure 4-1. CRITICALITY MODEL FLOWCHART (Continued)

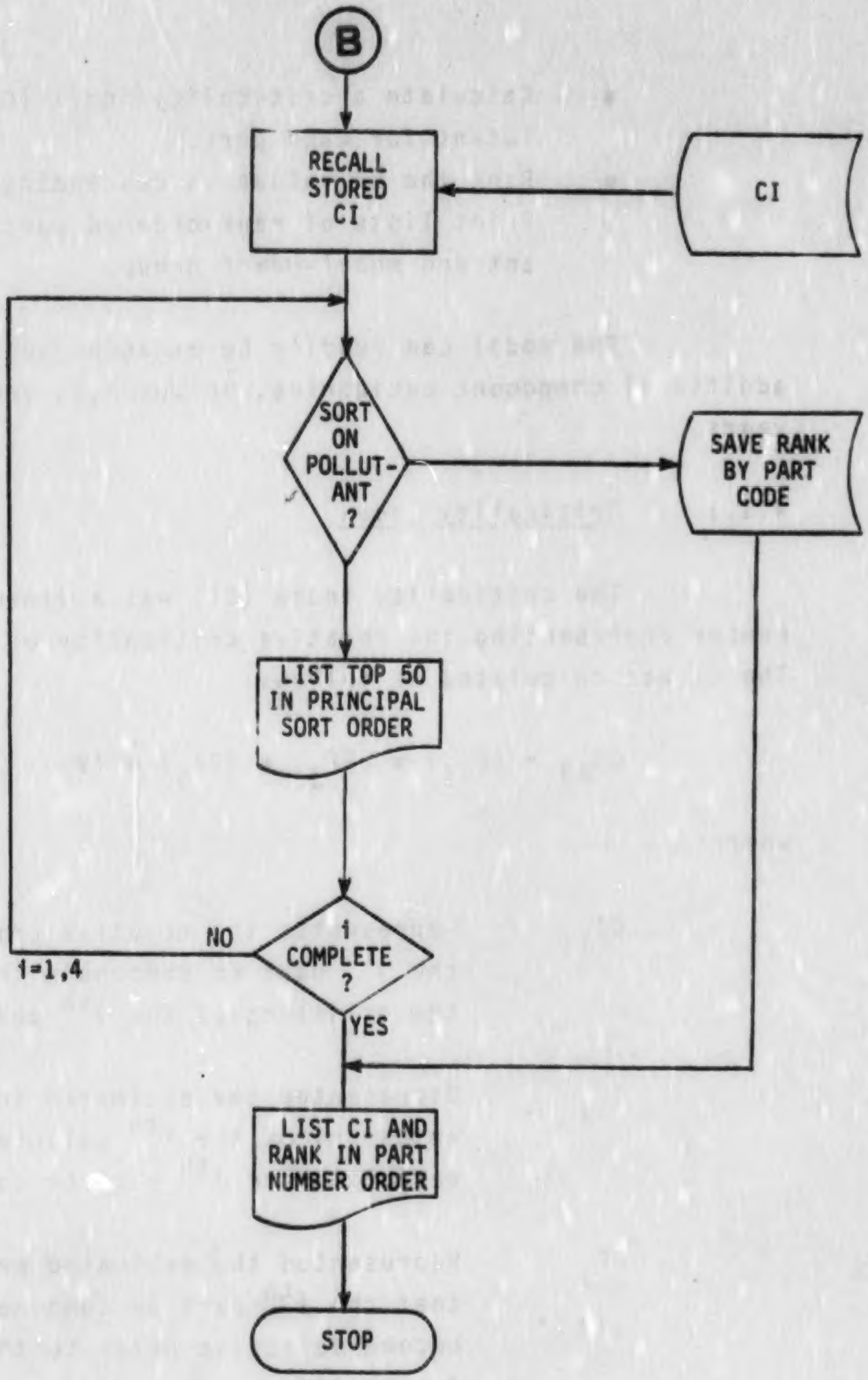

B
RECALL STORED CI
CI
SORT ON POLLUTANT ?
SAVE RANK BY PART CODE
LIST TOP 50 IN PRINCIPAL SORT ORDER
i=1,4
NO
i COMPLETE ?
YES
LIST CI AND RANK IN PART NUMBER ORDER
STOP

Figure 4-1. CRITICALITY MODEL FLOWCHART (Continued)

- Calculate a criticality index (CI) by pollutant for each part.
- Rank the CI values in descending order
- Print lists of rank-ordered parts by pollutant and model-years group.

The model can readily be expanded to include additional component categories, pollutants, and model years.

4.1.1 Criticality Index

The criticality index (CI) was a dimensionless number representing the relative criticality of each part. The CI was calculated as follows:

$$CI_{ij} = (E_{ij}) \bullet (PF_j) \bullet (PR_j) \bullet (V_j)$$

where:

CI_{ij}	Represented the relative criticality of the j^{th} part or component in affecting the emissions of the i^{th} pollutant.
E_{ij}	Represented the estimated impact on emissions of the i^{th} pollutant by a defect in the j^{th} part or component.
PF_j	Represented the estimated probability that the j^{th} part or component would become defective prior to the end of its design life.

PR_j	Represented the probability that the j^{th} defective component would not be repaired prior to the end of its design life.
V_j	Represented the sales volume factor for the j^{th} component.

4.1.2 Emission Increase Factors

The emission increase factors (E_{ij}) were based on the expected change in emissions with respect to the emission standards applicable to the engines or vehicles using the specific component. The values of E_{ij} and corresponding emission increase criteria are shown in Table 4-1.

Table 4-1. CRITERIA FOR EMISSION INCREASE FACTORS

E VALUE	EMISSION INCREASE
0.0	No change or decrease in emissions from defect (vehicle may be disabled by defect in this component).
0.1	Emissions may increase but probably not enough to fail standard.
1.0	Slight emission increase (enough to fail standards).
2.0	Moderate emission increase (about twice the standard).
5.0	Substantial emission increase (several times the standard).
10.0	Severe emission increase (order of magnitude higher than standard).

The emission increase factors were determined independently for pre-1975 (noncatalyst) and post-1975 (catalyst-equipped) vehicles since these model-year groups reflected significant differences in emission standards and control system configurations. The emission increase factors for each component were assigned on the assumption that other components were not defective.

For the HC criticality rankings, the evaporative emission increase factor for each component was combined with the corresponding exhaust emission increase factor as follows:

$$E_{HC} = E_{HC} + 1/3 \; E_{EVAP}$$

The smoke emission increase factors for each test mode were averaged to provide a composite smoke emission increase factor as follows:

$$E_{smoke} = \frac{E_{accel} + E_{lugging} + E_{peak}}{3}$$

4.1.3 Probability of Failure Factors

The probability of a component's failure (PF_j) prior to the expiration of its design life was estimated on the basis of durability data, available published data, and Olson's experience during inspection and maintenance studies. Probability of failure was based on defects and excluded failures due to tampering. The design life of each part or component was assumed to be 50,000 miles or the recommended replacement interval of the part, whichever was lower. Based on the available data and engineering judgement, a relative factor representing probability of component failure was assigned using the criteria shown in Table 4-2. The same PF_j factors were assigned to components for all model years.

Table 4-2. CRITERIA FOR PROBABILITY OF FAILURE FACTORS

PF VALUE	PROBABILITY OF FAILURE
0.01	Failure extremely unlikely during component design life - failure typically does not occur during vehicle's useful life (over 100,000 miles).
0.10	Failure very unlikely during component design life - failure typically occurs late in vehicle useful life (75,000 to 100,000 miles).
0.30	Failure unlikely during component design life - failure typically occurs between 50,000 to 75,000 miles.
0.50	Failure may occur during component design life.
0.70	Failure likely to occur during component design life.
0.90	Failure very likely to occur during component design life.

4.1.4 Probability of Repair Factors

The probability that a defective component would not be repaired (PR_j) prior to the end of its design life was based on the detectability of the failure and the nature of the component in relation to normal tune-up practice. Components which had noticeable performance effects (plugs) or were routinely replaced (condenser) had a low probability of remaining defective. However, defective components which were not normally serviced (thermal vacuum valves) or had no noticeable effect on performance (EVAP canister) would probably not be repaired. The same PR_j factor was assigned to all model-year vehicles. Based on available data and engineering judgement, PR_j factors were assigned using the criteria shown in Table 4-3.

Table 4-3. CRITERIA FOR PROBABILITY OF REPAIR FACTORS

PR VALUE	PROBABILITY OF REPAIR
0.10	Repair extremely likely due to severe performance impact.
0.30	Repair likely due to performance impact and routine diagnostic/service procedures.
0.50	Repair may occur depending on diagnostic/service procedure and skill.
0.70	Repair unlikely due to small performance impact or unusual failure mode.
0.90	Repair very unlikely due to small performance impact and unusual failure mode.

4.1.5 Sales Volume Factors

The sales volume factor (V_j) for each part was not readily available due to the large number of manufacturers and models of each component type. Therefore, V_j was based on determining component usage by engine family and then determining the sales of each engine family as follows:

$$V_j = \frac{\sum_{K=1}^{U_j} (M_k) \bullet (n_{jk}) \bullet (1+R_{jk}) \bullet (S_k)}{\sum_{K=1}^{P} (M_k) \bullet (S_k)}$$

where:

M_k Represented the number of vehicles of the k^{th} engine family.

n_{jk}	Represented the number of j^{th} components used on an engine of the k^{th} engine family.
R_{jk}	Represented the number of replacements of the j^{th} component required by the k^{th} engine family during its 50,000-mile design life.
S_k	Represented the scrapage factor of the k^{th} engine family in 1976.
j	Represented the component index (1 to 133).
k	Represented the engine family index (1 to P, U_j) P = engine families in population U_j = engine families with component j ($0 \leq U_j \leq P$)

In performing this study, the engine families listed below were excluded in order to reduce the amount of data required. Exclusion of these engine families was not believed to introduce significant error since similar basic engine components were used on these engines as on those which were included in the study.

- Light-duty gasoline engine families whose manufacturers produced less than 1 percent of sales in any given year.
- All light-duty diesel engine families.
- All heavy-duty gasoline engine families.
- All but the 15 most popular heavy-duty diesel engine families.

4.2 ASSIGNMENT OF CRITICALITY INDEX MODEL PARAMETERS

This paragraph describes the values of the CI model input parameters assigned to each OEM component. These values are based on the characteristic defect or failure mode described in Section 3. Pertinent literature is cited where available. However, many of the assigned values are based on engineering judgement. The resulting rank-ordered lists of emission-critical OEM components are presented and discussed in paragraph 4.3. Appendix B summarizes the input parameter values by part name.

4.2.1 Effect of Defect on Emissions

Each OEM component category was assigned an emission increase factor for each of the following pollutants:

- Gasoline Engines
  Evaporative hydrocarbons
  Hydrocarbons
  Carbon monoxide
  Nitrogen oxides

- Diesel Engines
  Acceleration smoke
  Lugging smoke
  Peak smoke (post-1974 model-year engines)

The smoke emission increase factors were assigned only to components on heavy-duty diesel engines. Components used only on gasoline engines were assigned 0.0 values for the smoke emission increase factors. Separate emission increase factors were assigned to early model-years (1972 through 1974 for light-duty, 1972 through 1973 for heavy-duty) and late model-years (1975 for light-duty, 1974 through 1975 for heavy-duty) to reflect different engine/emission control system configurations corresponding to the different emission standards.

4.2.1.1 Carburetion Systems

Carburetion systems included completely assembled carburetors, carburetor components, and carburetor (throttle) control devices. Complete carburetors were not treated in this analysis since the major components of the carburetor were each treated individually. Specific emission increase factors for HC, CO and NO_x are discussed below for the following components based on the functional description and characteristic defects described in Section 3.2. Similar emission increase factors were assigned to components in which the defect would have similar effect.

- Idle stop solenoid
- Throttle dashpot
- Throttle positioner
- Metering jets
- Metering rods
- Vacuum break valves
- Choke mechanism (except electric assists)
- Accelerator pump
- Power valve
- Gaskets
- Float and valve
- Idle adjustment screws
- Idle enrichment systems
- Fuel filter

Idle Stop Solenoid: The idle stop solenoid defect would result in excessive throttle closure (anti-dieseling) during idling. This results in excessively rich operation at idle. A defective idle stop solenoid was identified as the cause of emissions failure of a catalyst-equipped vehicle (Ref. 93). A recent study (Ref. 17) indicates that a 1 percent CO increase in idle CO concentration approximately doubles the hot 1972 FTP emissions of CO from all vehicles and HC emissions from catalyst vehicles. Emissions of NO_x from all vehicles and HC emissions from noncatalyst vehicles were not affected. These results generally confirm the CRC APRAC CAPE-13 study (Ref. 16) performed on pre-1972 model-year vehicles. Based on these data, the following emissions increase factors were assigned:

	HC	CO	NO_x
1972-1974	0.1	1.0	0.0
1975	1.0	1.0	0.0

Throttle Dashpot and Positioner: Defective dashpots result in more rapid throttle closure during deceleration. Defective throttle positioners result in full throttle closure during decelerations. These defects result in momentary enrichment (Ref. 3) causing high HC and CO during deceleration. No data was obtained which related defective dashpots or throttle positioners to increased emissions. However, it was assumed that the defect would be similar to overall idle enrichment except that catalysts would be able to reduce the HC increase. Therefore, the following emission increase factors were assigned to both throttle dashpots and throttle positioners:

	HC	CO	NO_x
1972-1974	0.1	1.0	0.0
1975	0.1	1.0	0.0

Metering Jets: Defective metering jets result in mixture enrichment and higher CO. However, except in the case of incorrect jet size installed in the carburetor, erosion of the jet by cavitation or entrained particulates is slow and the effect on emissions is small. No data exists relating jet size changes to FTP emissions. Therefore, engineering judgement was used to assign the following factors for defective jets:

	HC	CO	NO_x
1972-1974	0.1	0.1	0.0
1975	0.1	0.1	0.0

Metering Rods: Defective rods result in mixture enrichment similar to eroded jets. Since the rod position is adjustable, the consequence in terms of incorrect orifice size and metering rate is greater for rods than for jets. Therefore, larger CO emission increases were assigned to defective rods than to defective jets. The same factors were assigned to noncatalyst and catalyst vehicles since the effectiveness of the catalyst in controlling excessive emissions is balanced by more stringent standards:

	HC	CO	NO_x
1972-1974	0.1	2.0	0.0
1975	0.1	2.0	0.0

Vacuum Break Valves: Defective vacuum break valves result in normal thermostatic choke opening rather than load or temperature modulated opening. This results in longer and richer warm-up and higher cold-start emissions of HC and CO. The CO emission increase relative to the standards should be greater on catalyst-equipped vehicles than on noncatalyst vehicles because of the large weighting of cold-start emissions. The HC emission increase, however, should be small since the vacuum is above the throttle plate (Ref. 27). The following emission increase factors were, therefore, assigned:

	HC	CO	NO_x
1972-1974	0.1	0.1	0.0
1975	0.1	1.0	0.0

Choke Mechanism: Defective chokes cause higher HC and CO emissions due to fuel enrichening particularly during open-throttle operation. The degree of emission increase depends on engine size and emission control system. This defect may also result in accelerated catalyst aging for catalyst-equipped vehicles as well as higher emissions (Ref. 12, 16, 17, 70, 78, 92, 93 and 100). The HC/CO emission increase factors were, therefore, assigned as follows:

	HC	CO	NO_x
1972-1974	2.0	10.0	0.0
1975	2.0	10.0	0.0

Accelerator Pump: Defective accelerator pumps result in intermittent lean operation during the initial throttle opening of acceleration. This may result in momentary lean misfire and higher HC. Emissions of CO from non-catalyst-equipped vehicles will decrease due to the additional oxygen and dilution of the exhaust (Ref. 78). Catalysts should be able to partially oxidize the HC emissions, thereby, resulting in slightly higher CO emissions (Ref. 70). The following emission increase factors were, therefore, assigned.

	HC	CO	NO_x
1972-1974	0.1	0.1	0.0
1975	0.1	0.1	0.0

Power Valves: Defective power valves result in excessive fuel flow at all off-idle conditions. Although no specified data were obtained, the result is similar to choke failure (Ref. 70 and 78). Therefore, the same emission increase factors were assigned for power valves as were assigned for ~~accelerator pumps~~: chokes:

	HC	CO	NO_x
1972-1974	2.0	10.0	0.0
1975	2.0	10.0	0.0

Gaskets: Defective gaskets result in vacuum leaks and lean misfire at closed throttle (high vacuum). The resulting increase in mass emissions though is small due to the small effective size of the leak and because it occurs primarily during closed throttle (Ref. 27). No specific data on gasket failures were obtained, the failure is expected to be similar to lean misfire from defective accelerator pumps. Therefore, the following emission increase factors were assigned.

	HC	CO	NO_x
1972-1974	0.1	0.0	0.0
1975	0.1	0.1	0.0

Float and Valve: Defective floats result in excess fuel flow during all load conditions. However, the effect on emissions at idle generally is less than incorrect idle adjustment (and can be compensated for by idle adjustment), and is less than the choke or power valve defects under load. No data was obtained relating specific float level misadjustment to FTP emission levels. However, the same emission increase factors have been assigned to a defective float and valve as were assigned to defective metering rods.

	HC	CO	NO_x
1972-1974	0.1	2.0	0.0
1975	0.1	2.0	0.0

Idle Adjustment: Improper idle adjustment can result in either rich or lean operation. The emission increase depends on the degree of misadjustment, the engine size, and emission control system. Rich adjustment, however, is much more common as shown by surveillance and inspection programs (Ref. 12, 16, 78 and 94). The emission increase factors were based on the assumption of moderate maladjustment (i.e., 1 to 2 percent CO at idle) and were as follows (Ref. 16, 70 and 93):

	HC	CO	NO_x
1972-1974	0.1	1.0	0.0
1975	1.0	1.0	0.0

Idle Enrichment System: Defective idle enrichment systems can result in excessive enrichment at all temperatures rather than at low temperature only (Ref. 27). This is equivalent to excessively rich idle adjustment. The same emission increase factors as above were, therefore, assigned:

	HC	CO	NO_x
1972-1974	0.1	1.0	0.0
1975	1.0	1.0	0.0

Fuel Filter: The defect mode results in reduced fuel flow to the carburetor causing lean operation and power loss under heavy load conditions. On gasoline engines flow restriction may lead to slight increases in HC emissions but no change or decreases in CO and NO_x emissions. On diesel engines, flow restriction can lead to power loss but not increased smoke since excess air is already present (Ref. 2 and 3). The following emission increase factors were, therefore, assigned.

	HC	CO	NO_x	Smoke
1972-1974	0.1	0.0	0.0	0.0
1975	0.1	0.1	0.0	0.0

4.2.1.2 Ignition System

Defects in the ignition system can lead to misfire and increased HC emissions. Some defects can affect the timing of the ignition spark and, consequently, NO_x emissions. Some defects leading to misfire or changes in spark timing may also increase CO emissions due to the increased throttle opening which is required to maintain desired speed and load conditions. Catalysts are generally able to oxidize HC emissions more easily than CO. Therefore, some of the unburned fuel may be oxidized resulting in smaller increases in HC and larger increases in CO emissions than expected compared to noncatalyst-equipped vehicles.

Separate paragraphs are devoted to the following OEM ignition system components:

- Points
- Condenser
- Distributor cap
- Distributor rotor
- Distributor mechanical advance
- Distributor vacuum advance
- Spark delay valves
- Electronic ignition triggers
- Spark plugs
- Ignition wires
- Coils
- Ballast resistor
- Electronic ignition circuits
- Basic ignition timing

The above components can generally be divided into primary ignition components, secondary ignition components, and distributor timing components. In general, primary ignition component defects do not cause as severe misfire as a secondary ignition defect which may essentially disable one cylinder. Specific data relating defects to emission increases were not available for individual primary ignition system components. However, since misfire is distributed intermittently over all cylinders, the emissions increases should not be as severe as for plugs or wires.

Primary Ignition Components: The primary ignition system includes points, condensor, coil, ballast resistor and distributor drive mechanisms which affect point operation. These components were all assigned the same emission increase factors because specific data on each component was not available, and all components generally cause a random intermittent misfire in the secondary ignition system. The actual emission increase on any specific vehicle or engine depends on the deviation of the component from specification, the number of cylinders, and the emission control system configuration.

Misfire on pre-catalyst-equipped vehicles generally causes HC emissions to increase with little or no change in CO and NO_x (Ref. 12, 78, and 94). On catalyst-equipped vehicles, however, the catalyst should be able to partially oxidize the HC emission increase (Ref. 15) resulting in a small increase in both HC and CO. Emissions of NO_x should not be significantly affected by intermittent misfire (Ref. 7, 15, 35, and 70). Therefore, the following emission increase factors were assigned to the primary ignition components described above:

	HC	CO	NO_x
1972-1974	1.0	0.0	0.0
1975	0.1	0.1	0.0

Distributor Rotor and Cap: A defective distributor cap and/or rotor increases the resistance of the secondary ignition circuit and reduces the available firing voltage at the spark plug. No data was obtained relating rotor or cap failure to FTP emissions. However, frequent misfire on one or more spark plugs (usually the plug/wire with highest internal resistance) may result if severe cap or rotor deterioration occurs. Frequent misfire causes moderate increases in emissions of HC (Ref. 3, 7, 16, 70, 78, and 92). Changes in CO or NO_x emissions are small. Therefore, the following emission increase factors were assigned to both the rotor and cap:

	HC	CO	NO_x
1972-1974	2.0	0.0	0.0
1975	2.0	0.1	0.0

Distributor Mechanical/Vacuum Advance: Defective mechanical or vacuum advance including dual diaphragm advance results in incorrect or no spark advance as engine speed and/or load increase from idle (Ref. 3). This is equivalent to improper (retarded) basic timing which can effect HC, CO and NO_x emissions depending on engine speed and/or load condition. The change in timing due to a defective advance mechanism may lead to misfire but is more likely to affect the time of combustion with respect to valve opening. Emissions of HC decrease due to late firing and smaller surface to volume ratios. Emissions of NO_x decrease due to the combustion occurring at lower compression ratios than normal. Emissions of CO increase because additional throttle angle is required and mass flow rates are higher. The following emission increase factors were, therefore, assigned to distributor advance mechanisms.

	HC	CO	NO_x
1972-1974	0.0	0.1	0.0
1975	0.0	1.0	0.0

Spark Delay Valves: Defective spark delay valves result in normal vacuum advance during initial throttle opening. This increases NO_x emissions somewhat and may also increase HC emissions slightly (Ref. 3 and 27). Similar emission increase factors were assigned for spark delay valves as were assigned for advanced timing and defective OSAC valves since they result in advanced timing.

	HC	CO	NO_x
1972-1974	0.1	0.0	1.0
1975	0.1	0.0	1.0

Electronic Ignition Trigger: No data was obtained relating failures of the electronic ignition to emissions. Defective electronic ignition triggers, however, can cause intermittent misfire since a plug will not fire if the trigger signal is missing (Ref. 46). The same emission increase factors assigned to spark plug and wires were, therefore, assigned to electronic ignition triggers:

	HC	CO	NO_x
1972-1974	10.0	0.0	0.0
1975	10.0	0.1	0.0

Spark Plugs/Wires: Defective plugs or wires cause ignition misfire. Typically, one cylinder is affected because of an open or shorted wire or a fouled plug. This can result in continuous HC emissions, in excess of 2,000 ppm C_6, which is equivalent to 20 or more grams per mile by the FTP. In addition, for some catalyst-equipped vehicles, total misfire on one cylinder may damage the catalyst if continued for an extended period and if the over temperature protection system (air dump) fails. Emissions of NO_x may increase but not enough to fail (Ref. 16, 78, 92, 93, and 100). On catalyst vehicles, the excess HC emissions may be partially oxidized to CO. Therefore, the following emission increase factors were assigned to defective plugs and wires:

	HC	CO	NO_x
1972-1974	10.0	0.0	0.0
1975	10.0	0.1	0.0

Ignition Timing: Defective (advanced) basic ignition timing results in increased idle emissions and may also increase cruise emissions due to errors in total advance (Ref. 3 and 27). The CAPE-13-68 study (Ref. 16) showed that timing advance increased HC and NO_x mass emissions but decreased CO. These results were partially confirmed for catalyst vehicles in recent studies (Ref. 17 and 100) which showed that advanced timing decreased CO, did not significantly affect HC, and increased NO_x slightly. Other studies, however, showed that advanced timing increased HC and CO as well as NO_x (Ref. 92 and 98). Retarded timing reduces NO_x and generally increases HC and CO (Ref. 92, 98 and 100). The following emission increase factors were assigned for basic ignition timing since advanced timing is the most probable failure condition:

	HC	CO	NO_x
1972-1974	0.1	0.0	1.0
1975	0.1	0.0	1.0

4.2.1.3 Air Induction System

Defects in the air induction system can result in either excessively lean or rich carburetion depending on the component. The emissions-related components of the induction system are:

- Thermostatic Air Cleaner including shroud and hose, thermostat, vacuum motor, vacuum hoses, fresh air inlet

- Air cleaner element
- Turbochargers

TAC Shroud, Hose, and Thermostat: Failure of these components affects only the cold start FTP results. No data was available relating defects in these components to emissions. However, the expected affect is lean misfire due to mixture enleanment from unheated dense air (Ref. 3 and 27). The effect on CO and NO_x emissions is expected to be negligible. Vehicles equipped with catalysts are more sensitive to cold start emissions. Therefore, the following emission increase factors were assigned to these components:

	HC	CO	NO_x
1972-1974	0.1	0.0	0.0
1975	1.0	0.0	0.0

TAC Vacuum Hoses and Vacuum Motor; Defective vacuum hoses or vacuum motor produce a vacuum leak in the intake manifold in addition to preventing rapid warm-up. The leak is present at all operating temperatures and, therefore, has more effect on HC emissions than the other TAC components which only influence cold start performance (Ref. 3). The HC and CO emissions will probably decrease on noncatalyst vehicles but CO emissions may increase slightly on catalyst vehicles due to partial oxidation of the HC emissions. NO_x emissions will probably not be affected (Ref. 92 and 93). The following emission increase factors were, therefore, assigned:

	HC	CO	NO_x
1972-1974	0.1	0.0	0.0
1975	1.0	0.1	0.0

TAC Fresh Air Inlet: A defective TAC air inlet for underhood, or cool air, results in hotter than normal air being drawn into the engine. This will cause a decrease in air density and, consequently, mixture enrichment (Ref. 2). This will increase CO and HC emissions slightly, but decrease NO_x. No data was obtained on the relation of this defect to emissions. However, the HC and CO emissions increase for catalyst vehicles were assigned the same value as for non-catalyst vehicles since reserve activity of the catalyst should compensate for the slightly higher emissions. Therefore, the following emission increase factors were assigned:

	HC	CO	NO_x
1972-1974	0.1	0.1	0.0
1975	0.1	0.1	0.0

Air Cleaner Element: The air cleaner element is subject to clogging which reduces the air flow under any given vacuum. This has the effect of decreasing the air-fuel ratio which increases CO and HC emissions but decreases NO_x emissions. However, a previous study (Ref. 16), has shown that substantial restriction of the air cleaner is required before significant changes are observed in CO emissions. Catalytic reactors are expected to partially control CO emission increases. Some carryover of high CO into HC may also occur. The actual emission increase is highly dependent on the engine size control system configuration, and degree of restriction (Ref. 92, 92 and 100). Therefore, the following emission increase factors are assigned which are the same as those assigned for metering rods, float and valve in the carburetor:

	HC	CO	NO_x
1972-1974	0.1	2.0	0.0
1975	0.1	2.0	0.0

The air cleaner also can affect smoke emissions from diesel engines due to the fuel enrichment which occurs when the air cleaner is clogged (Ref. 2 and 3). This effect is independent of the model-year and is significant only for the acceleration and peak smoke measurements (Ref. 3). The following smoke emission increase factors were assigned:

	ACCEL	LUGGING	PEAK
1972-1973	1.0	0.0	-
1974-1975	1.0	0.0	1.0

Turbocharger: The turbocharger increases the volumetric efficiency of the engine due to pressurizing the intake manifold (Ref. 2). However, it only functions during acceleration or high load conditions. Defective turbochargers would be expected to reduce the air pumped through the engine and, thereby, result in mixture enrichment (Ref. 2). The smoke emission increase factors are shown below:

	ACCEL	LUGGING	PEAK
1972-1973	1.0	0.1	-
1974-1975	1.0	0.1	1.0

4.2.1.4 Fuel Injection Systems

Fuel injection systems are used in both gasoline and diesel engines. Fuel injection systems may be mechanically operated (MFI) or electrically operated (EFI). Gasoline engines use either MFI or EFI. Diesel engines, however, use MFI. Defects in these systems generally result in excess fuel supply leading to excessive CO, HC and smoke emissions. Conditions of insufficient fuel supply produce unacceptable driveability problems and are rapidly corrected by owners. Emission increase factors were, therefore, assigned for the more typical failure; i.e., excess fuel metering.

The following fuel injection components are discussed below:

- Accumulator
- Fuel pressure sensors/regulators
- Throttle linkage and valve
- Injection valves
- Air sensors/switches
- Temperature sensors/switches
- Injectors
- Triggering switches
- Starting valve
- Idle adjustment screws

Accumulator: The accumulator is not likely to fail. However, if it did fail, overfueling is the probable result due to pressure shock waves developing in the fuel lines (Ref. 3). This probably causes slightly higher smoke emissions as follows:

	ACCEL	LUGGING	PEAK
1972-1973	0.1	0.1	-
1974-1975	0.1	0.1	0.1

Fuel Pressure Sensor/Regulators: Incorrect fuel pressure is most likely to cause overfueling, particularly during acceleration. Incorrect fuel pressure is analogous to incorrect float setting. The peak smoke reading may also be high. High fuel injection pressure in gasoline engines would cause higher CO and slightly higher HC but lower NO_x on the FTP. Therefore, the following emission increase factors were assigned:

	HC	CO	NO_x
1972-1974	0.1	1.0	0.0
1975	0.1	1.0	0.0

	ACCEL	LUGGING	PEAK
1972-1973	1.0	0.1	-
1974-1975	1.0	0.1	1.0

Throttle Linkage and Valve: Incorrect throttle valve adjustment in mechanical injection systems will tend to overfuel all cylinders. This is particularly true for heavy-duty engines in which overfueling can increase the useful power of the engine. Higher smoke emission increase factors were assigned for late-model engines due to tighter standards. Overfueling occurs at all load conditions (Ref. 3 and 63). The following smoke emission increase factors were, therefore, assigned:

	ACCEL	LUGGING	PEAK
1972-1973	1.0	0.1	-
1974-1975	2.0	0.1	2.0

Injection Valves (MFI): Defective injection valves result in excessive fueling of individual cylinders under all operating conditions (Ref. 3). The most severe effect probably occurs during low load when the fuel flow is not completely shut off (Ref. 3). Therefore, the following emission increase factors were assigned:

	ACCEL	LUGGING	PEAK
1972-1973	1.0	1.0	-
1974-1975	1.0	1.0	2.0

Air Flow or Temperature Sensors/Switches (EFI): Characteristic defects in air or oxygen sensors/switches result in mixture enrichment either due to restricted air flow (auxiliary air regulator) or increased fuel flow (defective manifold vacuum switch, intake air flowmeter, or O_2 sensor). Failure of any temperature sensor results in overfueling because cold start enrichment continues at all times (Ref. 3 and 27). These failures are analogous to defective power valves and chokes in carburetors. The following emission increase factors were, therefore, assigned:

	HC	CO	NO_x
1972-1974	1.0	5.0	0.0
1975	1.0	5.0	0.0

Injectors-Solenoid (EFI): Defective injectors fail to shut off, thereby, dribbling fuel at all times into the intake manifold or port. This results in mixture enrichment of at least one cylinder (Ref. 3). The following emission increase factors were, therefore, assigned:

	HC	CO	NO_x
1972-1974	0.1	2.0	0.0
1975	0.1	2.0	0.0

Triggering Switches (EFI): The triggering switches are contacts in the distributor which signal the time with respect to TDC at which the fuel is to be injected (Ref. 3). Failure of the triggering switches tends to produce lean misfire particularly at high speed and load. Catalyst activity, however, partially oxidizes the increased HC to CO. Therefore, the following emission increase factors were assigned:

	HC	CO	NO_x
1972-1974	2.0	0.1	0.1
1975	2.0	1.0	0.1

Starting Valve: The starting valve is used for enrichening the mixture of gasoline engines during cold start. A defective starting valve enriches the mixture at all times. This is analogous to a partially closed choke (Ref. 3). Therefore, emission increase factors were assigned which are half of those assigned to chokes:

	HC	CO	NO_x
1972-1974	1.0	5.0	0.0
1975	1.0	5.0	0.0

Idle Adjustment: Idle air bleed screws are used on gasoline fuel injection systems for the same reason as on carburetors. The same emission increase factors were assigned for HC, CO, and NO_x as were assigned for carburetor idle adjustment.

	HC	CO	NO_x
1972-1974	0.1	1.0	0.0
1975	1.0	1.0	0.0

Idle fuel flow adjustments are also provided for diesel fuel injection pumps or throttle valves. These adjustments usually involve bypass pressure relief. Excessive idle fuel flow causes smoking during the lugging and deceleration modes of the FTP (Ref. 2 and 3). The following emission increase factors were, therefore, assigned:

	ACCEL	LUGGING	PEAK
1972-1973	0.1	1.0	-
1974-1975	0.1	1.0	2.0

4.2.1.5 Engine Systems

The following OEM engine components can affect emissions within the certification design life:

- Exhaust valves and associated components such as seals, lifters, springs, guides, cams, camshafts and timing chains.
- Piston rings.
- Head gaskets.

No data was obtained relating defects in these components to FTP emission levels. However, design and development information on the effect of valve operation on emissions was available in several references. Emissions from both gasoline and diesel engines are affected by defects in these components. Therefore, values were assigned to emission increase factors for HC, CO, NO_x, and smoke.

The components which control valve alignment and operation include lifters and springs, valve cams and camshafts, and valve guides. These components, if defective, cause the valves to open and close incorrectly resulting in loss of unburned mixture from one or more cylinders. This causes increased HC and smoke emissions. Defective valve seals and piston rings allow lubricating oil to enter the cylinders. This increases smoke and CO emissions because the heavy oils do not burn completely. Defective head gaskets may allow coolant to enter the engine. This results in quenching of the combustion process and increased emissions of HC, CO, and smoke. Catalyst vehicles may also experience a slight CO emission increase due to partial oxidation of the HC emissions (Ref. 3 and 15). The following emission increase factors were, therefore, assigned to all internal engine components using engineering judgment:

	HC	CO	NO_x
1972-1974	1.0	1.0	0.0
1975	0.1	0.1	0.0

	ACCEL	LUGGING	PEAK
1972-1973	1.0	1.0	-
1974-1975	1.0	1.0	1.0

4.2.1.6 Emission Control Systems

The same emission increase factors were assigned to similar emission control components even though they were used in different systems. For example, all vacuum hoses were assigned the same factors for HC since a vacuum leak may be created whether a hose is employed in EGR, TCS, or ignition advance applications. Similarly, transmission or speed sensors were assigned the same emission increase for NO_x whether they were used in SCS, TCS or EGR applications. Some devices may fail in more than one state. Emission increase factors were assigned for the failure mode with either the greatest probability of occurring or with the greatest effect on emissions. None of these emission control systems are used on diesel engines and, therefore, no smoke emission increase factors were assigned. The emission control systems considered were the following:

- Crankcase ventilation (PCV)
- Evaporative emission (EVAP)
- Air injection (AIR)
- Exhaust gas recirculation (EGR)
- Transmission/speed controlled spark (TCS)

- Orifice spark advance control (OSAC)
- Electronic spark control (ESC)
- Catalytic reactors (CAT)
- Manifold heat control (Heat riser)
- Electric assist choke
- Staged choke pulldown
- Decel valve
- Distributor vacuum deceleration valve
- Thermal vacuum valves
- Distributor starting solenoid
- Distributor vacuum valve

PCV Valve and Breather (Air Inlet): Restrictions of the PCV valve or air inlet filter to the PCV system cause mixture enrichment since the PCV valve contributes ventilation air flow to the intake. The CAPE-13-68 study (Ref. 16) found that NO_x-controlled vehicles were quite sensitive to PCV restriction for CO, slightly sensitive for HC and insensitive for NO_x. No specific data for catalyst-equipped vehicles were available. However, PCV restriction is similar to rich idle adjustment. The same emission increase factors assigned idle adjustment were, therefore, assigned to PCV valves and breathers:

	HC	CO	NO_x
1972-1974	0.1	1.0	0.0
1975	1.0	1.0	0.0

PCV and EVAP Vacuum Hoses: PCV or EVAP hose failure (rupture or looseness) results in evaporative emissions and possibly lean misfire. Under high load, crankcase vapors may be forced into the atmosphere. If an intake manifold vacuum hose fails, a lean misfire will result due to the high air flow at idle (Ref. 3). Catalyst vehicles have the same evaporative emission increase but slightly higher CO emissions due to partial oxidation of the hydrocarbons from misfire (Ref. 70 and 93). The following emission increase factors were assigned:

	EVAP	HC	CO	NO_x
1972-1974	10.0	0.1	0.0	0.0
1975	10.0	0.1	0.1	0.0

EVAP Canister: Failure of the carbon canister involves deactivation or saturation of the activated carbon so that fuel vapors pass through and out of the canister. No data was available on the relationship of the EVAP canister to emissions. However, no effect on exhaust emissions is expected. The following emission increase factors were assigned on the basis of engineering judgment:

	EVAP	HC	CO	NO_x
1972-1974	10.0	0.0	0.0	0.0
1975	10.0	0.0	0.0	0.0

EVAP System Components: In addition to the carbon canister and vacuum hoses, the EVAP system includes a fresh air filter, check valves, and sealed gas cap. No data was obtained relating defects in these components to emissions. Clogging or restriction of the EVAP fresh air filter, however, reduces the rate of purging and may reduce the activity and storage capacity of the carbon. Since clogging will probably not be complete, lower EVAP emissions increase factors are assigned than for a defective canister. Similar affects are produced by defects in the purge valves vapor/liquid separator, or fuel tank cap. The following emission increase factors were assigned to the above EVAP system components on the basis of engineering judgment:

	EVAP	HC	CO	NO_x
1974-1974	2.0	0.0	0.0	0.0
1975	2.0	0.0	0.0	0.0

Air Injection (AI) System: The AI system is disabled by breakage of the manifold, hoses, fan belts, or pump. Failure of the air injection system results in increased HC and CO emissions but no significant change in NO_x emissions. Failure of the AI system on catalyst vehicles causes a large increase in CO and HC emissions particularly in large engines due to loss of excess secondary air (Ref. 70, 93, and 100). The following emission increase factors were assigned to the air pump, manifold and hoses:

	HC	CO	NO_x
1972-1974	1.0	1.0	0.0
1975	2.0	5.0	0.0

Air Injection (AI) Filter and Check Valves: These AI system components can affect the performance of the system because they protect the pump either from entrained material or from backfiring which may occur in the exhaust manifold. Their failure, however, does not necessarily defeat the AI system. Therefore, the following emission increase factors were assigned on the basis of engineering judgment:

	HC	CO	NO_x
1972-1974	0.1	0.1	0.0
1975	1.0	1.0	0.0

Air Injection (AI) Bypass, Diverter or Gulp Valves: These valves are used to prevent backfiring in the exhaust system and catalyst overheating during engine malfunctions. Failure of the valves do not affect NO_x emissions, but slightly increase HC and CO emissions from noncatalyst vehicles. They have potentially great effect on HC and CO emissions from catalyst vehicles since the catalyst may be destroyed if these systems fail during an engine malfunction (Ref. 70, and 100). Therefore, the following emission increase factors were assigned:

	HC	CO	NO_x
1972-1974	0.1	0.1	0.0
1975	2.0	5.0	0.0

EGR Valve and Control Components: Defective EGR valves have negligible effect on HC and CO but may double or triple NO_x (Ref. 70, 92, 93 and 100). Valves may either become clogged (orifice) or stuck (vacuum activated) due to corrosion, diaphragm rupture or vacuum system failure (Ref. 70). The vacuum signal may be modulated for specific load, speed, and/or temperature conditions. The control components include thermal vacuum valves, solenoid valves, speed/transmission switches, temperature switches, and time delays. Failure of any one of these components will defeat the EGR system by denying vacuum to the EGR valve (Ref. 3 and 27). Therefore, the same emission increase factors assigned to EGR valves were also assigned to the above EGR control components:

	HC	CO	NO_x
1972-1974	0.0	0.0	2.0
1975	0.0	0.0	2.0

EGR Vacuum Amplifier and Vacuum Hoses: A defective vacuum amplifier or vacuum hose creates a manifold vacuum leak and also defeats the EGR system. Therefore, the same emission increase factors used for EGR valves were assigned to these vacuum components. The vacuum leak may increase HC emissions slightly. However, CO emissions will not increase due to the excess air and higher combustion temperatures present without EGR (Ref. 2, 3, and 27). Therefore, the following emission increase factors were assigned.

	HC	CO	NO_x
1972-1974	0.1	0.0	2.0
1975	0.1	0.0	2.0

EGR Vacuum Reducing Valve, Carburetor Spacer, and Back Pressure Sensor: Defective vacuum reducing valves and back pressure sensors reduce the vacuum signal reaching the EGR valve. This reduces EGR but not as much as complete failure of the vacuum signals. The carburetor spacer can become clogged so that EGR does not occur, particularly at a low pressure differential between intake and exhaust manifolds. Total blockage of the system is unlikely, however, unless severe oil burning occurs. There is no significant increase of HC or CO from these failures (Ref 3 and 27). Therefore, the following emission increase factors were defined for these components:

	HC	CO	NO_x
1972-1974	0.0	0.0	1.0
1975	0.0	0.0	1.0

EGR Check Valves: The EGR check valves hold the highest manifold vacuum achieved during certain operating conditions. This reduces the effectiveness of EGR but not as much as defective back pressure sensors or vacuum reducing valves (Ref. 3 and 27). Therefore, the following emission increase factors were assigned:

	HC	CO	NO_x
1972-1974	0.0	0.0	0.1
1975	0.0	0.0	0.1

TCS, SCS, ESC Solenoid Valves and Control Components: Vacuum solenoids are normally deactivated allowing vacuum advance signals to reach the distributor. During low speeds, the solenoids are activated to prevent vacuum advance for NO_x control. Failure of the solenoids produce normal vacuum advance at all times. This results in a slight HC emission increase and substantial NO_x increases. Emissions of CO are reduced since average timing is advanced from normal. Failure of components which activate the TCS, SCS, or ESC solenoids (speed switches, thermal vacuum valves, and time delays) also results in total defeat of the system. Therefore, the following emission increase factors were assigned:

	HC	CO	NO_x
1972-1974	0.1	0.0	2.0
1975	0.1	0.0	2.0

TCS, SCS, ESC Vacuum Hoses Failure of these vacuum lines results in manifold vacuum leaks and loss of vacuum advance. This results in reduced NO_x, slightly increased HC due to lean misfire, and higher CO due to retarded timing. The increased CO is proportionately higher on catalyst-equipped vehicles due to the lower standards and partial oxidation of the HC emissions. The following emission increase factors were, therefore, assigned (Ref. 3 and 70):

	HC	CO	NO_x
1972-1974	0.1	0.1	0.0
1975	0.1	1.0	0.0

CEC Solenoid: The CEC solenoid, used only on pre-1975 model-year vehicles, combined the vacuum solenoid and throttle positioner into one device. Failure of the solenoid prevents deceleration throttle modulation and vacuum advance at all times (Ref. 3 and 27). This increases HC and CO but reduces NO_x as shown below:

	HC	CO	NO_x
1972-1974	2.0	2.0	0.0

Orifice Spark Advance Control (OSAC) Valve: The OSAC valve delays the rate at which vacuum advance is applied to the distributor. Failure of this device results in normal spark advance at all times. This causes some increase in NO_x but small effect on HC and CO emissions. Vehicles equipped with OSAC also have other controls; i.e., EGR or TCS (Ref. 3 and 27). The following emission factors were, therefore, defined:

	HC	CO	NO_x
1972-1974	0.1	0.0	2.0
1975	0.1	0.0	1.0

Catalytic Reactors (CAT): Oxidation catalysts are subject to many failure modes. Destruction or deactivation of the catalyst substantially increases HC and CO emissions without affecting NO_x emissions. Therefore, the following emission increase factors were assigned to the catalyst active media assuming that other major defects (i.e., misfire), were not present (Ref. 72):

	HC	CO	NO_x
1975	2.0	2.0	0.0

Manifold Heat Control (Heat Riser): The heat riser aids in cold start warm-up by improving vaporization of the fuel. The heat riser is likely to stick in the closed position (hot manifold) which would delay the warm-up of the intake manifold and cause lean misfire due to vaporization of only the lighter fractions of the fuel (Ref. 2 and 78). This will increase HC emissions during the cold start (Ref. 16). Therefore, the following emission increase factors were assigned:

	HC	CO	NO_x
1972-1974	0.1	0.0	0.0
1975	1.0	0.1	0.0

Electric Assisted and Staged Pulldown Chokes: Failure of these components results in normal thermostatic choke opening. This increases emissions of HC and CO slightly but decreases NO_x (Ref. 27). The relative increase in CO emissions on catalyst-equipped vehicles is greater than on noncatalyst vehicles due to the relatively larger cold start effect and the lower emission standard.

	HC	CO	NO_x
1972-1974	0.1	0.1	0.0
1975	0.1	1.0	0.0

Decel Valve: Defective decel valves cause an increase in emissions of HC and CO during deceleration (high vacuum) conditions. Since this defect affects only deceleration conditions, the effect on composite FTP emission is relatively small. The same emission increase factors assigned to idle stop solenoids and rich idle mixture adjustment were assigned for the decel valve:

	HC	CO	NO_x
1972-1974	0.1	1.0	0.0
1975	1.0	1.0	0.0

Distributor Vacuum Deceleration Valve: The distributor vacuum deceleration valve applies full manifold vacuum to the distributor during deceleration (high vacuum). This increases engine speed to improve combustion during the deceleration period. Failure of the valve causes full vacuum advance at all times which will increase HC and NO_x but reduce CO emissions (Ref. 3 and 27). The following emission increase factors were assigned:

	HC	CO	NO_x
1972-1974	0.1	0.0	2.0
1975	0.1	0.0	2.0

Distributor Starting Solenoid: Failure of the distributor starting solenoid causes hard cold starting and prolonged cranking. This may increase cold start emissions due to flooding from excess gasoline. The following emission increase factors, therefore, were assigned on the basis of engineering judgment:

	HC	CO	NO_x
1972-1974	1.0	1.0	0.0
1975	1.0	1.0	0.0

Thermal Vacuum Valve: The thermal vacuum valve or switch is employed to switch spark advance from ported to manifold vacuum. When associated with EGR, TCS, SCS, CEC, or OSAC systems, the TVS has been included in those categories. Failure of a TVS results in normal spark advance at all temperatures. Therefore, the following emission increase factors were assigned:

	HC	CO	NO_x
1972-1974	0.1	0.0	2.0
1975	0.1	0.0	2.0

Distributor Vacuum Valve: Defective distributor vacuum valves result in small changes in spark advance because the vacuum source is shifted between the EGR and spark advance ports for improved driveability. Therefore, the following emission increase factors were assigned on the basis of engineering judgment:

	HC	CO	NO_x
1972-1974	0.1	0.0	0.1
1975	0.1	0.0	0.1

4.2.2 Probability of Component Failure Factor

Each component category was assigned a factor representing the probability of failure. Supporting data were either unavailable or contradictory. Therefore, the factors were assigned based on the general criteria discussed in paragraph 4.1.3. The same probability factors were assigned to similar components (i.e.; TVS, speed sensors) even if they were used in different applications. In determining the values for failure probability, consideration was given to the following factors:

- Operating environment (temperature, gas characteristics)
- Normal operating state (activated, deactivated)
- Operating principle (vacuum, mechanical, electrical)

4.2.2.1 Carburetion Systems

Carburetor components and control devices are generally quite reliable and are not usually reported as defective during durability testing (Ref. 35, 47, 72 and 73). In general, components operated mechanically or electrically are more reliable than vacuum-operated devices (Ref. 3).

The following electrically-operated carburetor components were, therefore, assigned a low probability of failure (PF=0.10):

- Idle stop solenoid
- Throttle positioner
- Electric assist choke heater
- Idle enrichment system

The following mechanical components were assigned a low probability of failure (PF=0.10) due to their passive function and low rate of deterioration. The fuel filter is a standard replacement part with recommended replacements every 2 years. These components are rarely, if ever, associated with emissions failure in OEM installations (Ref. 12, 16, 78, 94, 101 and 102):

- Metering jets
- Gaskets
- Fuel filter

The following mechanical- or vacuum-activated components were assigned a slightly higher probability of failure (PF=0.30) because of repetitive cyclical operation and sensitivity to adjustment:

- Throttle dashpot
- Metering rods

- Choke mechanism
- Float and float valve
- Accelerator pump
- Power valve
- Vacuum break valve
- Staged choke pulldown

The idle adjustment was assigned a high probability of failure (PF=0.90) based on a 50,000-mile design life and the expected degradation in carburetor idle air and fuel flow rates (Ref. 2, 3, 27, 94, 98 and 99).

4.2.2.2 Ignition System

Ignition system components, particularly spark plugs and ignition wires, are closely related to emissions and performance degradation. Components known to be emissions- and performance-sensitive are routinely serviced or replaced at intervals intended to occur before the expected failure. In many cases, PVIM studies have shown that components which appear marginal or defective actually have satisfactory emissions (Ref. 12 and 94).

The following primary ignition system components were assigned a low probability of failure (PF=0.10) on the basis of long design and service lives (Ref. 70), and broad performance tolerances before misfire actually occurs:

- Condenser
- Distributor mechanical advance
- Distributor drive mechanism
- Electronic ignition triggers
- Coils
- Ballast resistor
- Electronic ignition circuits

The following primary ignition system components were assigned a slightly higher probability of failure (PF= 0.30) based on more rapid deterioration due to severe operating conditions. These components, however, are designed to last the certification period (Ref. 70):

- Ignition wires
- Distributor cap and rotor
- Distributor vacuum advance diaphragms
- Dual diaphram vacuum advance mechanisms

The following components were assigned a relatively high probability of failure (PF=0.50) based on recommended replacement intervals which are shorter than the certification period:

- Points
- Spark delay valves

The following components were assigned a relatively high probability of failure (PF=0.70) based on durability data, garage experience and PVIM data.

- Spark plugs
- Basic timing adjustment

4.2.2.3 Air Induction System

The air induction system components are reliable and durable. With the exception of the air cleaner, all components have design lives in excess of 50,000 miles. The air cleaner is routinely replaced or serviced several times during the certification period. Therefore, low probability of failure (PF=0.10) was assigned for the air cleaner.

The following air induction components were assigned a low probability of failure (PF=0.10) based on their durability:

- TAC shroud and hose
- TAC thermostat
- Turbochargers

The following air induction components were assigned a slightly higher probability of failure (PF=0.30) based on more rapid deterioration due to repeated removal and reconnection or less durable construction.

- TAC vacuum motor
- TAC vacuum hoses
- TAC fresh air inlet

4.2.2.4 Fuel Injection System

The probability of failure of fuel injection components was based on a design life of 50,000 miles and engineering analysis of recommended maintenance practice and system design.

The following mechanical components were assigned a very low probability of failure (PF=0.01) based on durability and broad tolerance of emissions to performance variations:

- Accumulator
- Fuel pump
- Fuel distribution manifold

The following mechanical and/or electrical fuel injection components were assigned a low probability of failure (PF=0.30) based on adjustments or deterioration:

- Pressure sensors/regulators
- Air sensors/switches
- Temperature sensors/switches
- Triggering switches
- Electronic fuel injection

The following mechanical components were assigned a moderate probability of failure (PF=0.50) on the basis of the need for periodic adjustment or replacement due to mechanical deterioration:

- Throttle valve(s)
- Injection valves
- Solenoid injectors
- Starting valve
- Idle adjustment

4.2.2.5 Engine System

The following engine components were assigned a very low probability of failure (PF=0.01) since they should last considerably beyond the certification period:

- Valve cam lobes
- Valve guides
- Piston rings
- Gaskets
- Camshafts

A low probability of failure (PF= 0.10) was assigned to failure of the valve, valve seat, and valve seals since burned or leaking valves can be caused by numerous operating conditions before 100,000 miles.

A slightly higher probability of failure (PF= 0.30) is assigned to failure of the valve lifters and springs because of the need to periodically adjust some of these valve mechanisms on some engines.

4.2.2.6 Emission Control Systems

The probability of failure of emission control components depends on design life, typical maintenance practice, and operating environment. The following paragraphs are devoted to discussions of the probability of failure of specific component categories.

PCV Valve, and Fresh Air Filter - The PCV valve and filter is replaced on most engines every 2 years or 24,000 miles. The replacement is designed to occur prior to significant deterioration of the PCV system. Therefore, a low probability of failure was assigned (PF=0.30).

PCV and Other Vacuum Hoses - The PCV hoses and other vacuum hoses are normally not serviced during the certification period. The probable failure of these components is relatively low, even over the life of the vehicle. Therefore, the probability of failure was defined (PF= 0.10).

EVAP Canister - The carbon canister is replaced during the certification period on some engines. However, on most vehicles, the canister is not included in mandatory replacement. Activated carbon is durable, providing that it is purged adequately and pore spaces are not clogged with oil or particulates. Therefore, a relatively low probability of failure was assigned (PF=0.30).

EVAP Fresh Air Filter, Control Valves, and Fuel Tank Cap - These components of the EVAP system are reliable and have low probability of failure. The filter is replaced, usually every 2 years or 24,000 miles, even on systems where the carbon canister is not replaced. Therefore, a low probability of failure was assigned for these components (PF=0.10).

AI System - Components of the AI system are rugged and designed to be service free. AI failure is rarely identified in surveillance or PVIM programs. Therefore, a low probability of failure is assigned to all of the AI system components (PF=0.10) except for the distribution manifold and internal engine passages which were assigned the lowest probability of failure (PF=0.01).

EGR Valves, and Back Pressure Sensor - These two components are exposed to particulates, water vapor, acids, and hot gases in the exhaust system. They are subject to clogging, sticking, and corrosion. These systems may be visually inspected but are generally not subject to performance testing or mandatory replacement. Therefore, a high probability of failure was assigned to these components (PF=0.70).

Thermal Vacuum Valves, Vacuum Amplifier, Reducing and Check Valves - These components are not serviceable and not included in scheduled maintenance. They are generally reliable but are subject to sticking, diaphragm deterioration, and valve leakage. These components were assigned a relatively low probability of failure (PF=0.30).

Electrically-Operated Vacuum Solenoid Valves, Sensors, and Electronic Components - Vacuum solenoid valves are used in various systems to regulate vacuum signals. Various temperature, transmission, and speed sensors provide signals to operate solenoid valves, status lights, and electronic control circuits. Electrical components including ESC electronic modules, time delay and latching relays are highly reliable and not subject to scheduled maintenance. These electrical and electronic components were assigned a low probability of failure (PF=0.10).

Catalyst (CAT) Canister Body and Supporting Shell - The structural part of the catalyst is not subject to deterioration except through physical damage. A low probability of failure was therefore, assigned (PF=0.01).

Catalyst Active Media - The catalyst active media is subject to mechanical and thermal degradation. The probability of failure is relatively high, particularly if other malfunctions occur. Therefore, a moderate probability of failure was assigned (PF=0.50).

Heat Riser - The heat riser is exposed to hot, corrosive, and particulate laden exhaust gases. A relatively high probability of failure was, therefore, assigned (PF=0.70).

Decel Valve - The decel valve is a relatively reliable component once it has been correctly adjusted. No maintenance is specified and, therefore, a relatively low probability of failure was assigned (PF=0.30).

4.2.3 Probability of Repair Factor

The factor representing the probability of repairing a defective component was assigned using the criteria defined in paragraph 4.1.4. The probability of repair was based on the typical diagnostic and maintenance steps performed at scheduled maintenance, and on the detectability of the defect to the vehicle driver or mechanic.

4.2.3.1 Carburetion System

Most carburetion-related components, with the exception of the fuel filter and idle adjustment, are not included in scheduled maintenance. Carburetor rebuilding is usually performed when noticeable performance degradation occurs which can be attributed to leaking or sticking components. Emission increases can occur, however, before any obvious performance deterioration becomes apparent.

The following carburetion system components do not have a significant performance impact, are not included in normal scheduled or corrective maintenance, and are expensive to repair (Ref. 3). They were, therefore, assigned a high probability of no repair (PF=0.90).

- Metering jets
- Metering rods
- Choke
- Gaskets
- Float and valve
- Idle enrichment system
- Vacuum break valves
- Power valve
- Accelerator pump

The following carburetion system components may have a performance impact depending on the degree of failure and compensating adjustments made to idle speed and mixture. These components are also readily adjustable or replaceable (Ref. 3 and 27). They were assigned a moderate probability of no repair (PR=0.50).

- Idle stop solenoid
- Dashpot
- Throttle positioner

The following carburetion components are usually repaired during scheduled tune-ups. Mechanics are familiar with their replacement and importance to good performance (Ref. 3, 27, and 101). They were, therefore, assigned a low probability of no repair (PR=0.30).

- Idle adjustment
- Fuel filter

4.2.3.2 Ignition System

Ignition system defects leading to misfire are typically very noticeable and have a low probability of no repair. Basic ignition system maintenance is routinely performed including substantial preventive maintenance. Some components, however, are expensive (distributors) and may not be repaired due to consumer resistance until significant performance deterioration has occurred (Ref. 3 and 27).

The following ignition system components do not have a significant performance effect and are not part of normal ignition tune-up service; or, in the case of distributor drives, are quite expensive (Ref. 3). The probability of not replacing these components was, therefore, quite high (PF=0.90).

- Distributor drive
- Spark delay valve
- Coils
- Ballast resistor

The following components are not part of routine tune-up practice, but have a significant performance impact. They will probably be repaired if defective. Therefore, a moderate probability of no repair was assigned (PR=0.50).

- Mechanical advance
- Vacuum advance including dual diaphragm distributors
- Ignition wires
- Distributor rotor
- Distributor cap

The following components are included in routine tune-up practice and/or they have a significant performance impact. They are expected to be replaced if defective (Ref. 3 and 27). Therefore, a low probability of no repair was assigned (PR=0.10).

- Points
- Condenser

- Electronic ignition trigger switches
- Spark plugs
- Electronic ignition circuits
- Basic timing adjustment

4.2.3.3 Air Induction Systems

The air induction system regulates air flow into the engine. Physical defects may be noticeable in external components. They may not be repaired, however, due to relatively small performance degradation (Ref. 3). Therefore, the following components were assigned a high probability of no repair (PR=0.90).

- TAC shroud and hose
- TAC thermostat
- TAC vacuum motor
- TAC vacuum hoses
- TAC fresh air inlet

Turbochargers provide additional power and their failure is readily detectable (Ref. 3). They will probably be repaired in order to regain lost performance. Therefore, a low probability of no repair is assigned (PR=0.30).

The air filter is the only air induction component on which maintenance (replacement) is recommended and generally performed. However, there is no noticeable performance degradation and the rate of deterioration is low. Therefore, a moderate probability of no replacement was assigned for air filters (PR=0.50).

4.2.3.4 Fuel Injection System

Performance of the vehicle is relatively insensitive to defects in the fuel injection system since most defects result in overfueling. This is particularly true of mechanical fuel injection systems. Therefore, a high probability of no repair (PR=0.90) was assigned to the following components:

- Accumulator
- Fuel pressure sensors/regulators
- Throttle linkage and valve
- Injection valves
- Injectors
- Temperature sensors/switches
- Fuel distribution manifold
- Starting valve.

Several components can have significant effect on the performance of electronic fuel injection systems. These components regulate the timing and quantity of fuel delivered to each cylinder. Failure of the components may disable the vehicle or significantly alter the air fuel ratio over the range of speed and load conditions. These components were, therefore, assigned a low probability of no repair (PR=0.10).

- Air sensors/switches
- Triggering switches
- Electronic fuel injection control circuits

The idle adjustment on fuel injection systems is similar to carburetion systems. Therefore, the same probability of repair assigned to carburetor idle adjustment (PR=0.30) was assigned to fuel injection idle adjustments.

4.2.3.5 Engine Systems

The probability of repairing any engine system during the certification period is very low because of the high expense and relatively small effect on performance from typical defects. Therefore, the probability of no repair assigned to all engine system components was PR=0.90.

The probability of adjusting valve lash or lifter operation, however, is greater since this is recommended for some 4-cylinder engines. Therefore, the probability of repair assigned to lifter/springs was PR=0.50.

4.2.3.6 Emission Control Systems

The probability of repairing defective emission control systems depends strongly on the performance effect of the failure. Unfortunately, most emission control components do not have severe performance effects (i.e.; performance and fuel economy may improve, or the performance decrement is not detectable). In addition, failure of these components is relatively unusual and diagnostic procedures are complicated. Therefore, mechanics rarely attempt to diagnose emission control system failures unless ignition and carburetion components have been determined to be satisfactory and performance is still poor. Several exceptions to the above comments do exist, however. These are components external to the engine which have specified maintenance schedules and include the PCV valve, EVAP canister, AI pump and hoses and all vacuum lines. These and other components are discussed below.

PCV Valve - The PCV valve can cause rough idle if severely restricted (Ref. 3). However, the PCV valve is a scheduled maintenance component and subject to periodic replacement during the certification period. Therefore, a relatively low probability of no repair was assigned (PR=0.30).

PCV Fresh Air Filter - The PCV air filter is not normally serviced during the certification period, even though it may be recommended. Failure of this component is not likely to be diagnosed due to the small performance effect. Therefore, a high probability of no repair was assigned (PR=0.70).

EVAP Canister and Fresh Air Filter - The EVAP canister and its air filter do not have a noticeable performance affect if defective. However, the canister, or at least the filter, is scheduled for periodic replacement. Therefore, a moderate probability of no repair was assigned (PR=0.50).

PCV, EVAP, EGR, and Other Vacuum and Amplifier Hoses - All hoses providing vacuum signals can cause manifold leaks if defective. The vacuum leaks are likely to cause intermittent misfire expecially at idle and during deceleration. The misfire is likely to be corrected because of rough idle and vacuum hoses are an easy and inexpensive component to replace. Therefore, a relatively low probability of no repair was assigned to all vacuum hose defects. (PR=0.50).

EVAP Control Valves and Fuel Tank Cap - Failure of these components will have essentially no performance affect and cannot be readily diagnosed. Therefore, a high probability of no repair was assigned (PR=0.90).

AI Pump, Belts and Hoses - Failure of these components may create objectional noise leading to corrective maintenance. No vehicle performance degradation should be noticed, however, unless a belt fails and disables some other accessory. Driveability of the vehicle should not be affected, however. Therefore, a high probability of no repair was assigned (PR=0.70) to the belts, hoses and pump. The AI manifold and injector nozzle, however, were very unlikely to be repaired (PR=0.90) due to the fact that they were integral to the engine.

AI Check, Bypass and Diverter Valves - These components will result in backfiring in the exhaust system, if defective. No other performance effect such as degraded driveability should be noticed, however. A moderate probability of no repair was, therefore, assigned (PR=0.50) since the cost of replacing these components is relatively low.

EGR Valves - EGR valve inspection is included in most recommended maintenance schedules. However, clogging of the valve is likely to improve driveability so that there is little incentive to diagnose and correct defective EGR valves. A high probability of no repair was, therefore, assigned (PR=0.70).

EGR Back Pressure Valves - Back pressure valves have been used for only two model-years. No data is available on their performance. However, it is likely that they will become clogged and inoperative. Since they are not generally included in the recommended maintenance schedules, it is even less likely that defects will be detected than in the EGR valve itself. The probability of no repair was therefore, very high (PR=0.90).

Thermal Vacuum Valves, Vacuum Reducing and Check Valves - These valves regulate spark advance control and EGR systems. They are not included in recommended scheduled maintenance. Their failure is generally not detectable and may improve driveability under some conditions. A high probability of no repair was therefore, assigned (PR=0.90).

Vacuum Solenoid Valves, Temperature, Transmission, and Speed Switches and Relays - These components are not included in recommended scheduled maintenance. Failure is also unlikely and may lead to improved driveability. Therefore, the probability of no repair was quite high (PR=0.90).

Catalyst (CAT) - Replacement of the catalyst, either pellets or entire canister, is very unlikely due to high cost and difficulty in diagnosing a failure with typical garage instrumentation. Therefore, a high probability of no repair was assigned (PR=0.90).

Heat Riser - A stuck heat riser valve may create cold start problems. However, service on it is difficult due to its location and may involve removal of the manifold. Since normal hot running of the engine is not degraded, it is very unlikely that corrective repair would be performed. Therefore, a high probability of no repair was assigned (PR=0.90).

Decel Valve and Distributor Vacuum Deceleration Valve - The decel valves regulate air fuel mixture during deceleration. Defects in these valves generally are not detectable since they occur during deceleration. Idle performance can also be compensated for by idle mixture or speed adjustments. Therefore, a high probability of no repair was assigned (PR=0.90) to both components.

Electric Assisted Choke - A defective electric assisted choke will result in normal choke action and possibly improved driveability. Therefore, the probability of no repair was very high (PR=0.90).

4.2.4 Component Sales Volume

Component sales data were not directly available from industrial or governmental sources. This information was, therefore, estimated based on the following criteria:

- Sales or production volume of each engine family.
- Cumulative scrappage of vehicles by model-year.
- Number of each component installed in a single unit from each engine family.
- Number of replacements of each component during the certification design life.

4.2.4.1 Sales or Production Volume

Sales or production data were not available from the manufacturers, the EPA, or published documents in detail sufficient to precisely determine sales volume for this study because component usage within certification familes varied depending on body style and accessory equipment. Production data was provided by the EPA for some certification families. This data and published sales and production data were used to estimate the sales volume for families where data was missing. The following approach was used:

- Engine families were defined on the basis of detailed component usage decribed in the Mitchell Manual Emission Control Service Manuals (Ref. 27).

- Components used only on one model or body style within an engine family were deleted unless that model or body style represented a significant application of the engine family's production.

- Sales of California configuration engine families were assumed to be 10 percent of each model's published production.

- Published (Ref. 26) engine and transmission sales data by vehicle model were used to estimate the sales volume of engine families which were available in several vehicle models.

Not all engines and vehicle manufacturers were included in the analysis. Low production engine families were deleted including most imported light-duty vehicles, heavy-duty gasoline families, and most heavy-duty diesel families. Engine families which were deleted generally used similar systems and components as those families which were included. Therefore, the component usage data used in the study was generally representative. However, several gasoline engine families which were deleted used fuel injection systems. This reduced the relative ranking of EFI systems slightly. The diesel engine families which were selected represented popular engines used in many different trucks. Component usage was not significantly different in pre-1974 and post-1974 diesel engine families. Smoke emission reductions were achieved primarily by cylinder geometry and injector design modifications. Therefore, the relative ranking of components were the same for both model-year groups and not affected by deleting some families.

4.2.4.2 Scrappage Rate

The engine family production estimates were reduced to reflect vehicle scrappage as of July, 1976. Average scrappage rates for each model-year were calculated from published vehicle registration data and applied to all vehicles in that model-year. Unfortunately, published registration data was from 1 to 2 years late. The most recent data available (Ref. 26) which was published in April 1976, contained complete registration data only through the 1974 model-year.

The first interval with complete data was for the 1973 model-year scrappage between 1974 and 1975. This was taken as the first model-year interval. The second year scrappage rate was determined from the reduction in 1972 model-year registration data between 1973 and 1975. The percent reductions were then plotted and a smooth curve drawn through the origin. Scrappage rates were then determined from the plot as shown in Table 4-4 for each interval. For this study, the average scrappage rate was applied to the production data assuming that 1976 was the current year. Therefore, the scrappage applied to each model-year was as follows:

Table 4-4. SCRAPPAGE AS A FUNCTION OF VEHICLE AGE

MODEL YEAR	1st FULL YEAR	1st YEAR* REGISTRATION	1975* REGISTRATION	YEAR INTERVAL	ACTUAL SCRAPPAGE Percent	AVERAGE SCRAPPAGE Percent
1974	1975	9,763	9,763	0	0	0
1973	1974	11,269	11,332	1	0	0.5
1972	1973	10,158	10,098	2	0.59	2.0
1971	1972	8,915	8,549	3	4.11	4.0
1970	1971	8,888	8,339	4	6.15	6.5
1969	1970	9,299	8,339	5	10.32	10.0

*Registrations in thousands of vehicles

Model Year:	1976	1975	1974	1973	1972
Scrappage	0	0.5%	2.0%	4.0%	6.5%

4.2.4.3 Component Usage by Engine Family

The component usage for each engine family was obtained by reviewing the engine and emission control system descriptions contained in the Mitchell Emission Control Service Manuals (Ref. 27). The number of each component category was recorded with the following exceptions:

- Gaskets and vacuum hoses were assigned a 1 or 0 to indicate presence or absence. The actual number of individual components on the vehicle was not recorded.
- Engine mechanical components including valves, valve lifters, spring guides, seals, and piston rings were set equal to the number of pistons although the actual number of individual component may have been greater.

4.2.4.4 Component Replacement by Engine Family

The recommended frequency of replacement for each component category was determined from maintenance schedules. Only those components with mandatory replacement specified were assigned a component replacement factor in the model. The number of replacements was equal to the number of times a replacement was specified in 50,000 miles. If replacement was to be made every 6,000 miles, eight replacements were assigned to that component/engine family. Table 4-5 presents typical component replacements although the individual engine family component replacements may have differed depending on model-year and manufacturer.

Table 4-5. TYPICAL COMPONENTS WITH DESIGN LIFE LESS THAN 50,000 MILES FOR WHICH 1 OR MORE REPLACEMENTS ARE SPECIFIED

COMPONENT NAME	PART CODE	TYPICAL LIFE*	TYPICAL NUMBER OF REPLACEMENTS*
Points	2.1	12,000	4
Condenser	2.2	12,000	4
Spark Plugs	2.5		
Standard	2.5.1	12,000	4
High Energy	2.5.1	24,000	2
PCV Valve and	6.1.1	24,000	2
PCV Fresh Air Filter	6.1.3	24,000	2
EVAP Can and Carbon	6.2.1	24,000	2
EVAP Fresh Air Filter	6.2.3	24,000	2
Spark Delay Valve	2.3.7	12,000	4
Air Cleaner Element	3.2.0	12,000	4
Catalyst	6.9	25,000	1

*Actual component life was reported by engine family.

4.3 RANKING OF EMISSION-CRITICAL OEM COMPONENTS

The rankings of emission-critical components are shown in Table 4-6 for the 1975 model-year and Table 4-7 for the 1972 through 1975 model-years. These rankings are abstracted from the tables shown in Appendix A. Appendix A contains detailed rankings, including the criticality index values for early models only, late models only, and all models combined. Tables 4-6 and 4-7 present independent rank-ordered lists for HC, including evaporative emissions, CO, NO_x, smoke, and a composite ranking based on the absolute value of the criticality indices regardless of pollutant. Component rankings, except for smoke, each include the 25 most critical components. Smoke emissions were dependent on only 13 components identified in this study. Therefore, only those components are shown.

In general, the order of the rankings depended on model-year although the same components ranked in the top 25. Most components were critical to more than one pollutant, although not necessarily to the same degree. Critical components for HC and CO typically included the following:

- Secondary ignition components such as spark plugs and wires, and distributor cap and rotor.
- Cold start-related components such as choke, heat riser, and thermostatic air cleaner.
- Carburetion components affecting off-idle operation such as power valve, metering rods, float and needle valve, and air cleaner element.
- Components which affect idle air fuel ratio such as adjustment screws, PCV valve and filter, and vacuum hoses which can cause intake manifold leaks.

Table 4-6. CRITICALITY INDEX RANKING - LATE MODELS*
(Automotive Parts Study - EPA Contract No. 68-01-1957)

HC	CO	NO_x	SMOKE (Diesel)	COMPOSITE
Spark Plugs	Choke Mechanism	EGR Valves	Valve Lifter/Spring	Spark Plugs
Ignition Wires	Power Valves	EGR Thermo Valve	Valve Seals	Ignition Wires
CAT Active Media	CAT Active Media	Thermo Vacuum Valve	Exhaust Valves	Choke Mechanism
Choke Mechanism	Metering Rods	EGR Vacuum Amplifier	MFI Valves	Power Valve
Power Valves	Float and Valve	Spark Delay Valve	Air Cleaner Element	Valve Lifter/Spring
Heat Riser	Vacuum Break Valve	EGR Hoses/Seals	Valve Cam Lobes	EGR Valves
EVAP Canister	Idle Adjustment	Ignition Timing Adj	Valve Guides	CAT Active Media
Cap	PCV Fresh/Air Filter	EGR Carb Spacer	Piston Rings	Valve Seals
Rotor	Air Cleaner Element	EGR Backpress Sensor	FI Throttle Valve	Exhaust Valve
Idle Adjustment	PCV Valve	EGR Speed/Trans Sen	FI Idle Adjustment	Metering Rods
TAC Vacuum Motor	AI Hoses	OSAC Vacuum Orifice	Head Gaskets	EGR Thermo Vacuum
TAC Vacuum Hoses	Spark Plugs	EGR Solenoid Valve	Camshafts	Float and Valve
PCV Fresh Air Filter	Vacuum Advance	EGR Time Delay	FI Pressure Sens/Reg	Heat Riser
PCV Valve	AI Bypass Diverter	ESC Speed Switch	Turbocharger	EVAP Canister
PCV Hoses	Valve Lifter/Spring	TCS Temp Switch		MFI Valves
EVAP Hose	Ignition Wires	TCS Vacuum Solenoid		Cap
Valve Lifter/Spring	AI Pump/Belts	TCS Trans Switch		Rotor
TAC Shroud	Valve Seals	TCS Thermo Valve		Thermo Vacuum Valve
TAC Thermostat	Exhaust Valves	ESC Elec Module		Vacuum Break Valve
Mag/Opt Triggers	FI Starting Valve	TCS Time Delay		Idle Adjustment
EVAP Fresh Air	Heat Riser	SCS Thermo Valve		TAC Vacuum Motor
AI Pump/Belts	Mechanical Advance	EGR Temp Switch		TAC Vacuum Hoses
AI Hoses	Elec Assist Choke	SCS Vacuum Solenoid		PCV Fresh Air Filter
Valve Seals	AI Manifold	SCS Speed Switch		Air Cleaner Element
Exhaust Valves	AI Check Valves	EFI Trigger Switch		EGR Vacuum Amplifier

*Late models for HC, CO, and NO_x include 1975 and subsequent model years.
Late models for smoke include 1974 and subsequent model years

Table 4-7. CRITICALITY INDEX RANKING - ALL 1972 AND LATER MODELS
(Automotive Parts Study - EPA Contract No. 68-01-1957)

HC	CO	NO_x	SMOKE (Diesel)	COMPOSITE
Spark Plugs	Choke Mechanism	EGR Valves	MFI Valves	Spark Plugs
Ignition Wires	Power Valves	EGR Thermo Valve	Valve Lifter/Springs	Ignition Wires
Valve Lifter/Springs	Valve Lifter/Springs	Spark Delay Valve	FI Throttle Valve	Choke Mechanism
Choke Mechanism	Float and Valve	EGR Vacuum Amplifier	FI Idle Adjustment	Power Valves
Power Valves	Valve Seals	Thermal Vacuum Valve	Valve Seals	MFI Valves
Valve Seals	Exhaust Valves	EGR Hoses/Seals	Exhaust Valves	Valve Lifter/Springs
Exhaust Valves	Metering Rods	TCS Temp Switch	FI Pres Sens/Reg	EGR Valve
Rotor	Air Cleaner Element	Ignition Timing Adj	Air Cleaner Element	Float and Valve
Cap	PCV Fresh Air Filter	TCS Trans Switch	Valve Cam Lobes	Exhaust Valves
CAT Active Media	Idle Adjustment	TCS Vacuum Solenoid	Valve Guides	Valve Seals
EVAP Canister	CAT Active Media	EGR Solenoid Valve	Piston Rings	Metering Rods
Heat Riser	PCV Fresh Air Filter	TCS Time Delay	Head Gaskets	EGR Thermal Valve
Points	Vacuum Break Valve	OSAC Vacuum Orifice	Camshafts	Air Cleaner Element
Idle Adjustment	AI Hoses	EGR Carb Spacer	Turbocharger	PCV Valve
TAC Vacuum Motor	Valve Cam Lobes	EGR Backpress Sensor		Rotor
TAC Vacuum Hoses	Valve Guides	TCS Thermal Valve		Cap
Coil	Piston Rings	EGR Time Delay		Idle Adjustment
Ballast Resistor	Vacuum Advance	EGR Temp Switch		Spark Delay Valve
PCV Valve	AI Pump/Belts	EGR Speed/Trans Sw		CAT Active Media
PCV Fresh Air Filter	Idle Stop Solenoid	OSAC Vacuum Bypass		PCV Fresh Air Filter
PCV Hoses	Spark Plugs	ESC Speed Switch		EVAP Canister
EVAP Hoses	AI Bypass/Diverter	ESC Elec Module		Heat Riser
Valve Cam Lobes	Accelerator Pump	ESC Vacuum Valves		FI Throttle Valve
Valve Guides	Ignition Wires	ESC Temp Switch		FI Idle Adjustment
Piston Rings	Metering Jets	Dist Vac Decel Valve		EGR Vacuum Amplifier

- Emission control components such as catalyst and air injection components.

Emissions of NO_x were dependent on the performance of NO_x control systems, including the EGR valve and control components, and ignition advance control components such as vacuum advance units, delay valves, distributor components, TCS components, and carburetion components which can create lean operation.

Smoke emissions were related to 13 basic engine components on diesel engines. These components included engine valves and valve train components, piston rings, air cleaner, and fuel injection valves and control equipment.

Some components can cause emissions failures but were not ranked in the top 25 critical components. Table 4-8 summarizes those components which were found to cause a failure of one or more emission standard. This list includes those components shown in Table 3-1 and Appendix B for which one or more emission increase factor had a value of at least 1.0. As can be seen from Table 4-8, most of the components would result in a failure of one or more standards if defective.

Table 4-8. OEM COMPONENTS WHICH CAN CAUSE AN EMISSION FAILURE

PART OR COMPONENT	EMISSIONS FAILURE			
	HC	CO	NO_x	Smoke
Carburetor System				
Idle Stop Solenoid	x	x		
Throttle Dashpot		x		
Throttle Positioner		x		
Metering Jets		x		
Metering Rods		x		
Vacuum Break Valves		x		
Choke Mechanism	x	x		
Power Valves	x	x		
Float and Valve		x		
Idle Adjustment	x	x		
Heat Riser	x	x		
Idle Enrichment System	x	x		
Electric Assisted Choke	x	x		
Staged Choke Pulldown	x	x		
Ignition System				
Points	x			
Condenser/Capacitor	x			
Distributor Cap	x			
Distributor Rotor	x			
Mechanical Advance Mechanism		x		
Vacuum Advance Mechanism		x		
Distributor Drive Mechanism	x			
Magnetic or Optical Triggers	x			
Spark Plugs	x			
Ignition Wires	x			
Coil - Inductive	x			
Ballast Resistor	x			
Ignition Timing Adjustment			x	
Spark Delay Valve			x	
Air Induction System				
Thermostatically-Controlled Air Inlet	x			
Vacuum Motor and Hoses	x			
Air Cleaner Element	x	x		x
Turbochargers				x

Table 4-8. OEM COMPONENTS WHICH CAN CAUSE AN EMISSION FAILURE (Continued)

PART OR COMPONENT	EMISSIONS FAILURE			
	HC	CO	NO_x	Smoke
Fuel Injection System				
Fuel Pressure Sensors/Regulators		x		x
Throttle Linkage and Valve				x
Injection Valves				x
Air Sensors/Switches	x	x		
Temperature Sensors/Switches	x	x		
Injectors		x		
Triggering Switches	x			
Starting Valve	x	x		
Idle Adjustment Screws	x	x		
Engine System				
Valve Lifters and Springs	x	x		x
Cams	x	x		x
Valves, Guides and Seats	x	x		x
Seals	x	x		x
Rings	x	x		x
Gaskets	x	x		x
Camshafts	x	x		x
Emission Control System				
PCV Valve	x	x		
PCV Hoses	x			
PCV Fresh Air Filter	x	x		
AI Distribution Manifold	x	x		
AI Hoses	x	x		
AI Inlet Filter	x	x		
AI Check Valves	x	x		
AI Bypass/Diverter Valves	x	x		
AI Gulp Valves	x	x		
AI Pump	x	x		
EVAP Canister Body and Carbon Media	x			
EVAP Hoses	x			
EVAP Fresh Air Filter	x			
EVAP Vapor/Liquid Separator	x			
EVAP System Vapor Control Valves	x			
EVAP Fuel Tank Cap	x			
EGR Valves or Orifices			x	
EGR Hoses, Gaskets, Seals			x	
EGR Temperature-Controlled Valve			x	
EGR Solenoid-Controlled Valve			x	

Table 4-8. OEM COMPONENTS WHICH CAN CAUSE AN EMISSION FAILURE (Continued)

PART OR COMPONENT	EMISSIONS FAILURE			
	HC	CO	NO_x	Smoke
Emission Control System (Cont'd)				
EGR Temperature Switch			x	
EGR Speed/Transmission Switch			x	
EGR Time Delay Control			x	
EGR Vacuum Amplifier			x	
EGR Vacuum Reducing Valve			x	
EGR Carburetor Spacer			x	
EGR Back Pressure Sensor			x	
EGR Check Valve			x	
TCS Vacuum Solenoid			x	
TCS Vacuum Lines and Hoses		x	x	
TCS Time Delay Control	x		x	
TCS CEC Valve	x	x		
TCS Temperature Control Valve			x	
TCS Transmission Switch			x	
TCS Reversing Relay			x	
SCS Vacuum Solenoid			x	
SCS Vacuum Lines		x		
SCS Time Delay Control			x	
SCS Speed Sensing Switch			x	
SCS Temperature-Controlled Valve			x	
OSAC Vacuum Orifice Valve			x	
OSAC Vacuum Hoses		x		
OSAC Thermal Valve			x	
OSAC Vacuum Bypass Valve			x	
OSAC Temperature Sensor			x	
ESC Electronic Module			x	
ESC Hoses		x		
ESC Vacuum Valves			x	
ESC Temperature Sensing			x	
ESC Speed Sensing Switch			x	
CAT Body		x		
CAT Active Media	x	x		
Heat Riser	x			
Decel Valve	x	x		
Distributor Vacuum Deceleration Valve			x	
Distributor Starting Solenoid	x	x		
Thermal Vacuum Valve			x	

Section 5

SYMPTOMS OF FAILURE

This section describes the characteristic symptoms of failure for each of the emission-critical components listed in Section 4 for late-model; i.e., post-1975 model-year vehicles. Symptoms of component failure involve the owner's or driver's ability to detect whether a defect is present and the mechanic's ability to diagnose and correct it. In general, the driver is sensitive to certain performance criteria. Some owners or drivers may also be sensitive to changes in fuel economy, although emissions degradation can occur without noticeable loss in fuel economy. A few catalyst-equipped vehicles have warning lights to indicate abnormally high catalyst temperatures. While they do not identify the defect, they do indicate that a defect (typically misfire) does exist. In general, the detectability of a component's failure depends on its affect on one or more of the following performance characteristics:

- Hard starting.
- Rough idle and stalling.
- Poor driveability expressed by stumble, surge, hesitation, and poor acceleration.
- Pinging, knock, or backfiring.
- Poor fuel economy.
- Excess smoke.

A component may, of course, cause more than one symptom. Many components can cause the same symptom. Therefore, the presence of a symptom does not necessarily indicate a specific defective component. Table 5-1 lists many typical performance characteristics and the defects which can cause them (Ref. 3).

All component defects can be diagnosed and corrected if sufficient time and effort is expended. However, defects which do not degrade performance are unlikely to be serviced even if they are included in scheduled maintenance. In addition, all components affecting cold start performance are unlikely to be serviced since mechanics generally do not and cannot diagnose or service vehicles that are running cold. Diagnosis of the failure is required since many different component defects cause similar symptoms. Many garages, however, routinely perform ignition system tune-up (plugs, points, rotor, carburetor and timing adjustments) first and then attempt to diagnose any remaining performance defects.

The following discussion of symptoms of failure will be presented in the following order for those components found to be critical to HC, CO, NO_x or smoke emissions:

- Carburetion components
- Ignition system components
- Air induction components
- Fuel injection components
- Mechanical components
- Emissions control components

Table 5-2 summarizes the symptoms of failure for the emission-critical components and systems.

Table 5-1. POSSIBLE CAUSES OF COMMON PERFORMANCE PROBLEMS
(ABSTRACTED FROM REF. 3)

POSSIBLE CAUSE	PERFORMANCE PROBLEMS					
	Hard Starting	Engine Stalls	Power Loss	Poor Acceleration	High Speed Miss	Noise Dieseling
1. Weak battery	x					
2. Corroded or loose battery connections	x					
3. Loose ground connections for battery and/or engine	x	x				
4. Faulty starter or solenoid	x					
5. Moisture on ignition cables and distributor cap	x	x				
6. Faulty ignition cables	x	x				
7. Faulty coil	x	x		x	x	
8. Incorrect spark plug gap or dirty plugs	x		x	x	x	
9. Incorrect ignition timing	x		x	x	x	
10. Dirt or water in fuel line or carburetor	x		x	x	x	
11. Carburetor flooded	x					
12. Incorrect carburetor float setting	x	x	x			
13. Faulty fuel pump	x		x			
14. Carburetor precolating (vapor lock)	x					
15. Sticking choke	x					
16. Defective neutral starting switch	x					
17. Defective ignition switch	x					
18. Air cleaner obstructed	x		x			
19. Faulty emission control units	x		x			x
20. Faulty ignition distributor	x				x	
21. Idle speed set too low		x				
22. Incorrect choke adjustment		x				
23. Idle mixture too lean or too rich		x	x	x		
24. Intake manifold leak		x				
25. Worn distributor rotor		x	x		x	
26. Incorrect valve lash (mechanical lifters)		x	x		x	
27. Carburetor float needle valve inoperative		x				
28. Choke defective or incorrectly set		x				
29. Blown cylinder head gasket			x			
30. Leaking engine valves			x	x	x	

Table 5-1. POSSIBLE CAUSES OF COMMON PERFORMANCE PROBLEMS (Continued)
(ABSTRACTED FROM REF. 3)

POSSIBLE CAUSE	PERFORMANCE PROBLEMS					
	Hard Starting	Engine Stalls	Power Loss	Poor Acceleration	High Speed Miss	Noise Dieseling
31. Restricted exhaust system			x			
32. Weak valve springs			x	x		
33. Defective accelerator pump				x		
34. Sticking engine valves				x	x	
35. Faulty condensor					x	
36. Clogged carburetor jets					x	
37. Worn valve lifter					x	
38. Worn cams					x	
39. Worn valve guides					x	
40. Incorrect spark plug type						x
41. Combustion chamber deposits						x
42. High idle speed						x

Table 5-2. SYMPTOMS OF COMPONENT FAILURE

DEFECTIVE COMPONENTS	CRITICAL POLLUTANT				SYMPTOM OF FAILURE				
	HC	CO	NO_x	Smoke	Hard Starting	Drive-ability	Rough Idle	Fuel Economy	Back-Firing
Carburetion System									
Choke Components	x	x			x	x		x	
Metering Rods		x				x		x	
Float and Valve		x			x	x	x	x	
Power Valve	x	x			x	x		x	
Electric Assist Choke		x							
Idle Adjustment	x	x					x	x	
Vacuum Break Valve		x					x		
Ignition System									
Plugs/Wires	x	x			x	x	x	x	
Cap/Rotor	x				x	x	x		
Electronic Triggers	x				x	x	x		
Timing Adjustment			x			x		x	
Advance Mechanisms		x				x		x	
Air Induction System									
TAC Components	x				x		x		
Air Cleaner		x						x	
Vacuum Hose Leaks	x					x	x		
Turbocharger				x		x		x	

Table 5-2. SYMPTOMS OF COMPONENT FAILURE (Continued)

DEFECTIVE COMPONENTS	CRITICAL POLLUTANT				SYMPTOM OF FAILURE				
	HC	CO	NO_x	Smoke	Hard Starting	Drive-ability	Rough Idle	Fuel Economy	Back-Firing
Fuel Injection System									
EFI Trigger Switch			x		x	x	x	x	x
EFI Starting Valves		x				x		x	x
Injection Valves				x	x	x	x	x	
Pressure Reg/Sensors				x		x		x	
Mechanical System									
Valve Components	x	x		x		x	x	x	
Rings				x		x	x	x	
Gaskets				x		x	x	x	
Emission Control System									
Catalyst	x	x							
PCV Components	x	x					x		
EGR Components			x				x		
EVAP Components	x						x		
AI Components	x	x					x		x
Heat Riser	x	x			x	x	x		
TCS/SCS Components			x						
Spark Delay Valves			x						
Thermal Vac Switches			x						

5.1 CARBURETION COMPONENTS

In general, the carburetion system components which have significant impact on emissions do not have significant performance symptoms. Exceptions to this are carburetor defects which result in lean misfire which can create noticeable performance deterioration. Improper adjustment or failure of the accelerator pump, power valve, float, metering rods or idle adjustment can result in mixture lean-out during acceleration and resulting stumble, surging, and hesitation. The choke can also cause lean misfire and detectable driveability degradation if it fails to come on during cold starts. However, this is not a frequent choke failure mode compared to sticking closed or failing to open rapidly or fully. Typical failure modes for the other components also tend to produce rich operation rather than lean operation.

The carburetion components which ranked high in criticality included the following:

- Choke mechanism
- Power valves
- Float and valve
- Metering rods
- Vacuum break valves
- Idle adjustment
- Electric assist choke

The above components have failure modes which produce rich operation and, consequently, they are critical to HC and CO emissions. The failures (except delayed warm-up) would probably be detected by emissions inspection. However, performance degradation would not be noticeable since engines are presently designed to operate near the lean combustion limit. Consequently, engines can tolerate significant mixture enrichment before any performance degradation, resulting from rich misfire, is detected.

Carburetor problems are generally subtle and may be difficult to isolate. Carburetor rebuilding is also fairly time-consuming. Many garages do not attempt to repair carburetors and instead recommend that a replacement (either new or rebuilt) carburetor be installed. Exceptions to the above are the choke, throttle linkage, and idle mixture adjustments which are easy to perform and do not require removing or disassembling the carburetor.

Diagnosis of carburetor malfunctions is most effectively accomplished by using a dynamometer and infrared analyzer to determine the modal failures. This is helpful in determining whether the accelerator pump, power valve, metering jet, float level, or choke is defective. However, few garages use dynamometers and only some have exhaust gas analyzers. Typical diagnostic procedures involve first repairing or verifying correct performance of the ignition system and then checking carburetor adjustments to specifications. Typical components which may be incorrectly adjusted or worn include float, metering rod, accelerator pump, power valve, metering jets, gaskets, choke, throttle dashpot, throttle positioner, idle-speed and mixture screws.

5.2 IGNITION SYSTEM COMPONENTS

Ignition system components are typically critical to HC emissions, although some component failures also can increase CO or NO_x emissions. Ignition failures are the most readily detected defect due to engine vibration or bouncing which occurs when a cylinder misfires. Ignition misfires cause momentary power loss which can be detected as rough running. A defective ignition system can also cause hard starting and stalling. Ignition misfire usually becomes more severe under load since the entire ignition system is stressed more than at idle. However, cruise misfire is more difficult to detect since the higher engine speed smooths out engine vibration and bounce. Misfire usually develops gradually. Therefore, it may be difficult to detect intermittent misfire until it becomes rather frequent. The following ignition components create similar symptoms of failure, including poor acceleration, stumble, and rough running:

- Spark plugs
- Ignition wires
- Rotor
- Cap
- Electronic ignition triggers

Advanced ignition timing is emission-critical for NO_x. Unfortunately, timing defects are difficult to detect unless they become very severe. Advanced basic timing can cause pinging or knock. Retarded timing can decrease fuel economy and acceleration performance. Vacuum and mechanical advance failures have the same general effect as retarding the basic timing and are critical to CO emissions. Therefore, the same level of detectability applies to advance failures as applies to incorrect basic timing.

Routine ignition tune-up is the "bread and butter" of the automotive repair industry. The ignition system is the easiest to diagnose and the one most effectively repaired. Most garages have ignition analyzers and scopes with which to diagnose and isolate defects. These instruments provide a means of determining whether a single plug is misfiring, whether ignition cables are grounded or open, whether the coil is defective or whether the points (if equipped) are burned, pitted or improperly adjusted. The mechanic, unfortunately, does not have a means to simulate high load unless he has a dynamometer. Many mechanics, however, road test vehicles, particularly in response to specific owner complaints. The road test enables the mechanic to isolate specific modal failures which may indicate carburetion or ignition defects.

5.3 AIR INDUCTION COMPONENTS

The air induction system components which were emission-critical included the thermostatic air cleaner (TAC), air cleaner element, and turbocharger (diesel). The TAC components influence the rate of engine warm-up and smoothness of the cold idle. Defects in the TAC which also create vacuum leaks may result in lean misfire at idle. This would be detected as a rough idle with a tendency to stall even when hot. TAC components were critical to HC emissions due to lean misfire.

The air cleaner element does not have a performance or driveability impact. Routine service practice includes preventative replacement of the air cleaner whenever it appears dirty, even though emissions may not be adversely affected. Severely restricted air cleaners can increase fuel consumption. The increase, however, is not likely to be detected by the average motorist. Air cleaner testers are available. However, recent data indicate that visual inspection is probably satisfactory since 75 percent restriction may be required before a significant HC or CO emission increase occurs (Ref. 94 and 100).

A defective turbocharger produces a loss of power and increased fuel consumption (Ref. 63 and 67). These two factors are probably apparent to owners and drivers, particularly, if the vehicle is operated frequently near its maximum power rating where the turbocharger is most effective.

5.4 FUEL INJECTION COMPONENTS

Mechanical fuel injection components were critical only to smoke emissions. The performance symptom of failure is primarily decreased fuel economy. The characteristic defect of the emission-critical fuel injection components all produce rich mixtures. Since these components are used in diesel engines, increased smoke emissions would be a detectable symptom.

Electronic fuel injection starting valves and triggering switches were emission-critical to CO and NO_x, respectively. A defective starting valve is probably not detectable by the driver unless it fails to operate causing hard starting. The more critical failure mode is for it to remain operating at all times causing mixture enrichment. Defective triggering switches, however, will lead to lean mixtures and possible misfire. This will probably be detected by the driver.

Diagnosis of the fuel injection system defects involves verification of adjustments of the fuel pressure and throttle or injection valve operation. Electronic fuel injection components can be checked for continuity and specified resistance.

5.5 MECHANICAL COMPONENTS

Emission-critical mechanical components included valves and valve train, piston rings, and head gaskets. Defects in the valves may be detected by a misfire at idle, loss of power and acceleration or by engine noise. Some engines may develop noise if the valve lifters or lash are improperly adjusted. The symptom of misfire due to leaky exhaust valves is difficult to distinguish from ignition misfire, however, unless specific diagnostic procedures are followed.

Piston rings may be defective in addition to, or instead of, the exhaust valves. This failure can be detected by specific diagnostic procedures but, generally, cannot be distinguished from defective valves by the owner. Defective rings may cause excess blowby or excess oil consumption depending on the ring which fails. If excess oil consumption occurs, the defective rings may be detected by the owner or driver.

Defective head gaskets may cause oil or water to enter the cylinder. The head gasket defects cannot be distinguished by the owner or driver from other mechanical or ignition defects which cause similar performance degradation.

5.6 EMISSION CONTROL COMPONENTS

Most of the emission control components were found to be emission-critical. These components are discussed in the following order:

- PCV system
- EVAP system
- Air injection system
- EGR system
- TCS system
- SCS system
- ESC system
- OSAC system
- Catalyst
- Thermal vacuum valves
- Electric assist choke
- Heat riser

Most emission control system components do not usually provide obvious performance degradation to indicate that they have failed.

Diagnosis of emission control defects is normally performed after conventional engine, ignition, or carburetion failures have been corrected. This diagnosis involves functional tests of electrical, mechanical and vacuum components. Failures which cause vacuum leaks (i.e., vacuum hoses and amplifiers), however, may produce lean misfire at idle which would be detected as rough idle and possible stalling.

5.6.1 PCV System

The PCV valve and hoses may result in rough idle due to slow engine speed if they become sufficiently clogged. The PCV system is tested for vacuum and flow rate to verify free flow. The PCV valve is also a standard replacement component and is frequently replaced as a preventative repair.

5.6.2 EVAP System

The EVAP system does not have obvious failure symptoms and cannot be readily diagnosed except to verify that vapor hoses and vacuum lines are tight. The EVAP fresh air filter is replaced periodically and should be replaced if dirty. The EVAP system can produce excessive air flow if the check valve sticks open. This gives the symptom of a vacuum leak and will probably be compensated by enrichening the idle mixture or increasing the idle speed. Diagnosis of a stuck check valve is performed by listening for valve action as vacuum is applied and removed.

5.6.3 Air Injection System

The air injection system components may create unusual noise either in the affected component (i.e., belt or pump), or backfiring as a result of failure of the diverter or bypass valves. Air injection system diagnosis is performed by checking for correct component function. The air pump function is checked by applying vacuum to the bypass valve and listening for the air discharge. The check valve can be inspected by attempting to blow through it.

5.6.4 EGR and Timing Modulation Systems

Components affecting EGR or vacuum advance (TCS, SCS, ESC, OSAC) generally fail in a manner which provides equal or better performance than when the components are functioning. This is because normal advance signals are provided at all times when the components fail. Normal advance usually provides better part-throttle acceleration than retarded advance. Similarly, defective EGR components will disable the EGR system, resulting in less hesitation and stumble than may occur with EGR.

The EGR valve and vacuum control valves can be tested by observing valve operation when vacuum is applied. The valve may be removed for visual inspection if a defect is suspected and the valve diaphragm is operating. The valve can then be tested to ensure that it is not clogged.

The electrically-operated components of the TCS, SCS, and ESC systems can be checked by making electrical tests of continuity and resistance at specified test points. The vacuum control devices can be checked to ensure that valves open and close properly or delay vacuum changes the specified amount. These components regulate vacuum advance under specified conditions. Overall, system function can be determined by measuring total advance under various transmission and rear wheel conditions. The vehicle can be tested by raising the rear wheels off the ground and running at several unloaded speeds.

5.6.5 Catalyst Systems

Impending catalyst failure or failure of other components resulting in over-temperature of the catalyst is indicated by the catalyst warning light provided on some vehicles. This warning informs the driver that a defect condition exists which requires corrective action but does not define the defect. A defective catalyst, however, does not degrade performance and will usually not show an over-temperature warning since the activity of the catalyst will be depressed.

The catalyst cannot be directly tested without performing emissions measurements. However, a defective catalyst may provide low idle and 2,500 rpm readings if the basic idle mixture is lean, there are no other ignition or carburetion defects present, or the vehicle is equipped with air injection. A quick diagnostic test is to pull a plug wire and allow misfire on one cylinder to occur for a few minutes. A defective catalyst will result in 1,500 to 2,000 ppm HC emissions at idle. A functioning catalyst will reduce this to several hundred ppm HC.

5.6.6 Thermal Vacuum Valves

Thermal vacuum valves are usually included in timing modulation or EGR systems to regulate their performance according to engine temperature. Failure of these valves will have no appreciable effect on vehicle performance since normal spark advance and no EGR will usually be provided.

Thermal vacuum valve function can be checked when the fluid temperature is known. This can be done by measuring the coolant temperature, if convenient, or by removing the valve and placing it in water known to be cold (ice) and hot (boiling). Thermal vacuum valves also have a nominal position at normal engine temperatures. This position can be tested by checking for flow or vacuum through the nominally open path. Some manufacturers specify a functional check using engine rpm in response to changes in vacuum advance.

5.6.7 Electric Assist Choke

Defective electric assist chokes do not affect performance since normal thermostatic choke opening occurs. This provides slightly longer choke operation, richer mixture and smoother engine operation. Providing that other defects are not also present, the small increase in choke operation will have no effect on fuel economy. The electric assist choke heater can be tested for continuity and specified current flow. A defective electric assist choke will either produce no current flow at normal ambient conditions or nominal current flow at low temperature.

5.6.8 Heat Riser

A stuck heat riser will affect cold idling and acceleration because hot gases are not provided to promote rapid warm-up and vaporization of the fuel. This causes misfire which is detected as rough idle, hesitation, and stumble until the intake manifold is heated by conduction from the engine block. The heat riser can be mechanically tested to verify free movement. A free heat riser will generally operate correctly. A frozen heat riser will generally be stuck open causing a rough cold idle and delayed warm-up.

Section 6

RECOMMENDED TESTING

Components that were recommended for testing are discussed in this section. No heavy-duty diesel components were recommended due to the relatively low criticality of smoke-related components compared to the gaseous pollutants. The 25 original equipment (OEM) components selected for testing are discussed in paragraph 6.1. The test protocol recommended for the 25 OEM components is discussed in paragraph 6.2.

6.1 SELECTION OF COMPONENTS

The components selected for testing included fundamental ignition and carburetion components which affect vehicle performance and emissions. Data on some of these components have been reported in the literature. However, controlled experiments on catalyst-equipped vehicles were not reported for most of these components. Other components recommended for testing may be included in on-going or planned restorative maintenance and characterization programs and, therefore, may be subsequently deleted. Some of the recommended components do not have obvious symptoms of failure but their impact on emissions is critical enough to warrant inclusion in the Phase III test program. Other components were not well documented in the literature and the Phase III testing provides an opportunity to obtain these data.

Table 6-1 summarizes the components selected for testing and the suggested functional range over which they should be tested. Several components have more than one basic operating design. One each of these multiple configurations is suggested where appropriate.

6.1.1 Carburetion System Components

The following six carburetion components were recommended for testing on both air injection and nonair injection-equipped vehicles.

- Choke
- Float and valve
- Power valves
- Idle adjustment
- Metering rods
- Vacuum break valve

The other major carburetor components (gaskets, accelerator pump, throttle positioners, dashpots, and metering jets) are not recommended for testing due to their low criticality as OEM components.

6.1.1.1 Choke

The choke has several failure modes. Adjustment of the thermostat or choke linkage may be incorrect. The operating linkage may be bent or stuck preventing choke opening. The thermostat or electric assist heater may be defective resulting in delayed choke opening. Two choke defects are, therefore, selected for testing:

- Choke plate stuck closed
- Choke thermostat set two index marks rich (delayed opening)

Table 6-1. COMPONENTS RECOMMENDED FOR TESTING

COMPONENT	DEFECT	VARIABLE RANGE
Carburetion System		
1. Choke	Improper Adjustment	Normal Opening - Delayed Opening
2. Float and Valve	Improper Float Level	1/8" Low - 1/8" High
3. Power Valve	Stuck Open or Ruptured Diaphragm	Operational - Failed
4. Idle Adjustment	Improper Mixture	1/2 Turn In - 1/2 Turn Out
5. Metering Rod	Improper Adjustment	1/8" Low - 1/8" High
6. Vacuum Break Valve	Ruptured Diaphragm or Loose Vacuum Hose	Operational - Failed
Ignition System		
1. Spark Plugs	Electrode Deterioration	Wide Gap - Fouled
2. Wires	Cable Deterioration	Open - Grounded
3. Cap	Terminal Corrosion or	New - Old
4. Rotor	Terminal Erosion	New - Old
5. Vacuum Advance	Ruptured Diaphragm or Loose Vacuum Hose	Operational - Failed
6. EI Mag Trigger	Deteriorated	New - Old
7. Basic Timing	Improper Adjustment	SPEC -10^0 - SPEC $+10^0$
Air Induction System		
1. Thermal Air Inlet	Ruptured Diaphragm or Loose Vacuum Hose	Operational - Failed (Open)
Mechanical System		
1. Valve Adjustment	Improper Lash	Specification - 1/16" Excess
2. Exhaust Valve	Burned or Eroded	New - Old
Emission Control System		
1. Heat Riser	Stuck	Operational - Failed (Open)
2. Catalyst	Melted (Overheated)	Operational - Failed
3. Air Injection System	Hose or Pump	Operational - Failed
4. PCV Valve	Clogged	Operational - Failed (Closed)
5. Spark Delay Valve	Stuck	Operational - Failed (Open)
6. EGR Valve	Stuck	Operational - Failed (Closed)
7. Backpressure Sensor	Clogged	Operational - Failed
8. EGR Thermal Valve	Stuck	Operational - Failed (Closed)
9. Thermal Vac Valve	Stuck	Operational - Failed (Open)

6.1.1.2 Float and Valve

Float adjustment is critical to correct carburetor metering. Float adjustment is most likely to be high, although low float level is also possible. Three float settings are recommended for testing: specification, 1/8-inch low, and 1/8-inch high. The range of float adjustments is reasonable because significant driveability (lean) or emissions (rich) impacts would occur.

6.1.1.3 Power Valves

Power valves may be either vacuum or mechanically operated. A representative carburetor using both designs should be tested. The vacuum- operated power valve would be tested in operational and failed (ruptured vacuum diaphragm) configurations. The mechanically-operated power valve would be tested when set to specification and when held open by incorrectly adjusted linkage.

6.1.1.4 Idle Adjustment

Setting the idle adjustment on catalyst-equipped vehicles can be difficult, particularly if a tap is not provided upstream of the catalyst. The idle adjustment is a basic step in current tune-up practice. It is, therefore, likely that some misadjustment of the mixture will occur for mechanics who attempt to set idle in the same manner as for noncatalyst vehicles. The idle adjustment range is restricted, however, by limiter caps on the rich side and lean misfire on the lean side. The idle adjustment parameter would, therefore, be made by setting the idle one turn rich and one turn lean of the as-received adjustment.

6.1.1.5 Metering Rods

The metering rods are operated by the throttle linkage and are adjusted to select the correct metering jet size for the load condition. The metering rods would be tested at the following settings: specification, 1/8-inch low, 1/8-inch high. This range of adjustments is reasonable and creates significant driveability (lean) or emissions (rich) degradation.

6.1.1.6 Vacuum Break Valve

The vacuum break valve provides vacuum modulated choke opening to reduce the mixture enrichment under high vacuum conditions. The characteristic failure of the vacuum break valve is a ruptured diaphragm which prevents load modulated choke opening and may also introduce a vacuum leak. The vacuum break valve would be tested in a normally operating mode and a failed mode simulated by a disconnected vacuum line.

6.1.2 Ignition System Components

The following ignition system components are recommended for testing on both air injection and nonair injection-equipped vehicles:

- Spark plugs
- Ignition wires
- Distributor cap
- Distributor rotor
- Vacuum advance unit
- Electronic ignition trigger circuit
- Basic timing adjustment

6.1.2.1 Spark Plugs

Spark plugs are a routine tune-up component and have been included in numerous previous studies. However, plug failure and its relationship to increased emissions on catalyst-equipped vehicles has not been tested under controlled conditions using the FTP.

The characteristic defect of spark plugs is the electrode gap. This normally increases as plugs age due to electrical erosion. The increased gap increases the required firing voltage and reduces the spark firing time. Oil burning or rich mixtures can result in plug fouling which closes the gap and results in a shorted plug in which the spark does not fire. Spark plugs should be tested in three configurations: specified plug gap, all plugs set to twice the specified plug gap to simulate aged plug, and one plug shorted to simulate fouling in one cylinder.

6.1.2.2 Ignition Wires

Ignition wires are subject to two failure modes: breakage at terminals and grounding through the insulation. An open wire creates a high resistance for the spark voltage to cross. The plug usually fires but the firing time and energy discharged through the plug is low which causes misfire at high load and speed. The high potential which must be reached to fire the plug may cause arcing to ground or cross firing in the distributor cap. Similar failure occurs with a grounded ignition wire in which a wire has touched the exhaust manifold and melted the insulation. This defect is characterized by low firing voltage and causes misfire at idle. Therefore, the following wire conditions should be tested: normal (new) wire, one grounded wire, and one broken wire with high internal resistance.

6.1.2.3 Distributor Cap

The distributor cap is subject to several failure modes: terminal corrosion, carbon tracking leading to low resistance paths to ground or to other terminals, and wear or breaking of the primary high voltage terminal. These defects occur in old distributor caps. Therefore, this defective component's effect on emissions should be tested by comparing emissions from a defective distributor cap removed from a vehicle to emissions from a new cap.

6.1.2.4 Distributor Rotor

The rotor has the same failure modes as the cap. Carbon tracking can occur across the rotor to the grounded distributor shaft. Corrosion and electrical erosion of the rotor terminals can also occur. This defective component should be evaluated by testing an old rotor compared to a new one.

6.1.2.5 Vacuum Advance

The vacuum advance is critically related to emissions because permanent loss of vacuum advance (i.e., retarded timing) requires additional fuel flow to compensate for the more inefficient combustion. Vacuum advance is disabled by failures of the vacuum advance diaphragm. This failure mode can be simulated by disconnecting the vacuum line to the advance unit. A baseline test would be performed with the advance unit operational to evaluate the change in emissions. Some failures of the vacuum control valves or circuits of the TCS, SCS, and ESC systems can also cause loss of spark advance.

6.1.2.6 Electronic Ignition Magnetic Triggers

Breakerless electronic ignition systems are widely used in post-1975 model-year vehicles. The timing signal to fire each cylinder is detected electromagnetically. Failure of the magnetic timing bar is not likely. However, the electronic circuits which sense the trigger pulse and cause the coil to discharge, may become defective due to corrosion, temperature cycling, or vibration. Detection of the trigger signal then becomes intermittent which results in random misfire on all cylinders. This component defect should be evaluated by testing a new and an old triggering circuit. The old triggering circuit would be determined to have been defective, or an intermittent misfire could be programmed into the vehicle.

6.1.2.7 Basic Ignition Timing

Most studies of basic timing misadjustment has been performed on pre-catalyst vehicles; or using hot start tests. The range of 10^{o} timing advance and retard from specification should be tested to evaluate the effect of incorrect timing.

The other emissions-related ignition system components ranked relatively low in criticality for post-1975 model-year vehicles. These components include points, coil, resistor, distributor drive and mechanical advance. The misfire conditions these components create should be adequately represented by the use of the secondary ignition component defects which cause intermittent misfire (wide plug gap, high resistance wires, defective cap or rotor, defective advance mechanism and defective EI trigger).

6.1.3 Air Induction System

The only air induction component recommended for testing is the thermostatic air cleaner (TAC) vacuum hoses or vacuum motor. This failure introduces a vacuum leak and prevents heated air from entering the carburetor during cold start. The TAC failure would be evaluated by testing with and without the TAC vacuum hose disconnected. Other TAC components are not recommended for testing since they were not as emission-critical as the vacuum components.

The air cleaner is not recommended for testing since it is only moderately emission-critical due to low probability of failure and high probability of repair. In addition, considerable data is available which indicated that air cleaner restriction is not strongly related to FTP emission levels on catalyst vehicles.

6.1.4 Fuel Injection System

No fuel injection components are recommended for testing since they ranked low in emissions criticality. Fuel injection is used on only a small percentage of the current U.S. vehicle population.

6.1.5 Mechanical Components

Two exhaust valve characteristics are recommended for testing: valve adjustment, and burned valves. Valve adjustment is an important scheduled maintenance item for vehicles with mechanical valve lifters (typically, 4-cylinder engines). On these vehicles, the valve lash or clearance of the valve linkage must be adjusted to allow proper spacing for thermal and mechanical expansion and elongation of the various components. Excessive lash results in noisy valve operation and insufficient valve opening. Insufficient lash holds the valves open too long, permitting unburned gases to escape from the cylinder. Valve lash is set by adjusting screw stops on the rocker arm. Evaluation of improper valve adjustment would be made by comparing emissions of a vehicle with all cylinders set to correct lash compared to all cylinders set to 1/16-inch shorter lash.

Burned exhaust valves can result from normal operation of the engine over extended mileage accumulation and is a relatively common defect in high mileage vehicles. Burned valves would be evaluated by testing a vehicle with nominal valve condition determined by a compression check. This would be compared to the vehicle tested with one valve burned or ground to cause half of the nominal compression. Other mechanical components (rings, head gaskets, cams and cam shafts) are not recommended for testing due to low criticality and probability of failure within the certification period.

6.1.6 Emission Control Components

Nine emission control components are recommended for testing due to their expected impact on emissions. Only two components can cause detectable performance degradation: heat riser and PCV valve. The other components, however, were included since relatively little data is available regarding their impact on emissions from catalyst-equipped vehicles. The components recommended for testing are the following:

- PCV valve
- Air injection system
- EGR valve
- EGR thermal vacuum valve
- EGR back pressure sensor
- Thermal vacuum valve

- Spark delay valve
- Catalyst
- Heat riser

6.1.6.1 PCV Valve

The PCV valve fails when it is clogged by oil or particulates. Failure of the PCV valve would be evaluated by testing the nominally functioning PCV system and the PCV hose plugged.

6.1.6.2 Air Injection System

On vehicles equipped with air injection, the effect of a failure of the air injection system would be evaluated by disconnecting the air delivery hose and comparing the emissions to the normal system.

6.1.6.3 EGR Valve

The EGR valve fails if the vacuum hose, vacuum amplifier, or valve diaphragm are defective. In addition to loss of EGR, a vacuum leak is introduced. Ported EGR vacuum is proportional to throttle opening and vacuum leaks do not have significant affect on air fuel ratio; therefore, vacuum system failure only defeats EGR. However, manifold vacuum-activated EGR valves are closed by vacuum at idle and opened by spring action as vacuum decreases during acceleration. These valves can create idle lean misfire in addition to defeating EGR. The test of the EGR valve would be based on the manifold vacuum operated valve and would involve disconnecting the vacuum line at the EGR valve. Two tests would be performed, one with normally functioning EGR, and one with EGR disconnected.

6.1.6.4 EGR Thermal Vacuum Valve (EGR-TVV)

Several vehicles use a thermal vacuum valve to disable EGR during the cold start to improve driveability. Failure of this valve to open defeats EGR at all operating temperatures. The ported vacuum EGR valve failure is also similar to this defect since ported vacuum leaks do not cause lean misfire. The defects of both a stuck EGR-TVV and defective ported vacuum EGR valve will be evaluated by testing a vehicle with normal EGR-TVV and with the EGR line disconnected and plugged.

6.1.6.5 EGR Backpressure Sensor

The backpressure sensor modulates EGR in proportion to load. The sensor can be clogged or disabled by the hot and corrosive exhaust gases. This defect would be evaluated by testing a vehicle with normally functioning EGR and with the backpressure sensor's exhaust probe plugged.

6.1.6.6 Thermal Vacuum Valve

The thermal vacuum valve selects full vacuum advance rather than throttle, speed, or transmission modulated advance during cold or hot engine temperatures to promote higher engine speed. Failure of the valve to switch to modulated vacuum advance results in more spark advance on average during the FTP. This defect would be simulated by routing the vacuum lines so that manifold vacuum is always connected to the distributor. The defect and nominal vacuum routing would be tested to evaluate the effect of the defect.

6.1.6.7 Spark Delay Valve

The spark delay valve fails when the check valve remains open due to dirt or diaphragm rupture. This results in normal vacuum advance. The alternative failure, restricted or clogged valve orifice is analogous to disabled vacuum advance and is not considered further in this component category. The defect would be evaluated by testing vehicles with a nominal spark delay valve and with the valve removed from the vacuum advance hose.

6.1.6.8 Catalyst

Catalyst defects sufficient to cause emissions failure are unlikely unless some other ignition or carburetor defect has occurred which subjected the catalyst to excessive temperature. Even after the primary defect has been corrected, the defective catalyst remains and contributes to higher emissions than normal. To evaluate this defect, misfire would be established and continued during loaded operation until continuous catalyst temperature and raw exhaust emissions of HC have increased to indicate probable catalyst failure. The test sequence would then be performed without the misfire and compared to baseline emissions prior to the misfire.

6.1.6.9 Heat Riser

The heat riser is most likely to fail in the hot exhaust position which prevents rapid intake manifold warm-up. This defect is not well documented in the literature for catalyst-equipped vehicles and is expected to degrade cold start performance. This defect would be evaluated by testing vehicles with normally functioning heat riser and the heat riser jammed in the open position.

6.2 TEST PROTOCOL

The original equipment components selected for testing would all be subjected to the following general test protocol:

- Select representative test vehicles.
- Set all components to nominal specifications.
- Precondition test vehicle.
- Perform baseline tests.
- Establish defect condition.
- Precondition test vehicle.
- Perform defect condition tests.
- Perform restorative maintenance.
- Precondition test vehicle.
- Perform baseline test.
- Retest or perform additional restorative maintenance if second baseline emissions differ by more than 25 percent for HC, CO, and NO_x from first baseline test.

Various aspects of the test protocol are discussed in the following paragraphs.

6.2.1 Vehicle Selection

Test vehicles would be selected to represent typical weight classes and engine sizes equipped with the specific component to be evaluated. Where applicable, one vehicle with each of the following catalyst emission control systems should be tested for each component:

- Pelleted catalyst with air
- Pelleted catalyst without air
- Monolith catalyst with air
- Monolith catalyst without air

Testing is not recommended on pre-1975 model-year or noncatalyst-equipped vehicles since they represent small and decreasing fractions of the vehicle population.

6.2.2 Preconditioning

Preconditioning should be performed by accumulating 300 miles of freeway driving followed by approximately 10 minutes of surface street driving, or the first 505 seconds of the LA-4 driving schedule. Each vehicle would be preconditioned prior to baseline and defect testing. Preconditioning and cold soak would be performed in accordance with 40 CFR 85.076-12b for vehicles receiving the FTP.

6.2.3 Test Fuel

All preconditioning and testing would be performed with tank fuel.

6.2.4 Inspection and Maintenance

Each vehicle would be fully inspected prior to each test series to ensure that the basic engine adjustments are correct, that the ignition and carburetor systems are functioning normally, and that all vacuum, vapor, and air hoses are correctly routed and connected. During each test series, only the specific component under study would be adjusted or disabled.

6.2.5 Emission Tests

Ideally, the full FTP should be used to clearly define emission changes resulting from component defects since the criteria for emission-criticality includes failure of one or more of the FTP emission standards. However, FTP testing is expensive and, for those component defects which cause large emission increases, a short inspection test is probably adequate and cost-effective to confirm that emissions have increased significantly. Therefore, a short test sequence is recommended for most components, with FTP testing recommended only for those components which have significant effects on cold start operation.

6.2.5.1 Short Tests

Considerable data on the relationship between various short tests and the FTP have been, and are currently being, developed by the EPA. Although numerical relationships between short tests and the FTP are not precise, significant emission increases on short tests indicate a probable FTP failure. However, a vehicle which passes a short test may still fail the FTP.

In order to minimize the possible errors of emission by the short test, the following two short tests are recommended:

- Clayton Key Mode Test
- Federal 9-Mode CVS Test

The Key Mode test is recommended because it provides modal emission results. The Federal 9-Mode is recommended since it simulates the FTP. A separate idle test is not recommended, however, since the Clayton Key Mode test includes an idle mode. Each of the selected components would be tested using these cycles. An emission increase of 100 percent in any mode or in the Federal 9-Mode composite would constitute a significant increase. As an alternative criteria, the EPA Project Officer could establish failure limits for each test.

The components listed below are recommended for testing using the short tests only. These components are expected to have significant increases in hot running emissions which would be detected by the short tests. If increases are not observed, it is likely that FTP emissions would not be significantly altered by the defective component. These components include the following:

- Carburetion System
  Float and valve
  Power valve
  Metering rod
  Idle adjustment

- Ignition System
  Spark plugs
  Wires
  Cap
  Rotor
  Vacuum advance
  Electronic ignition triggers
  Basic timing

- Engine Mechanical System
  Valve lash
  Exhaust valves

- Emission Control System
  Catalyst
  Air injection system
  PCV valve
  Spark delay valve
  EGR valve
  EGR back pressure sensor
  EGR thermal vacuum valve
  Distributor thermal vacuum valve

6.2.5.2 FTP Tests

Several components have a significant effect on cold start or cold running emissions. Defects in these components may cause an FTP emissions failure, but not necessarily affect short test emissions which are measured when the vehicle and catalyst are warmed up. The following components would receive the FTP in addition to the short test:

- Carburetion System
  Choke
  Vacuum break valve

- Air Induction System
  Thermal (heated) air inlet

- Emission Control System
  Heat riser

6.2.5.3 Test Procedures

The FTP should be performed in accordance with 40 CFR 85.076-12b. The Federal 9-Mode test should be performed in accordance with 40 CFR 85.076-12b except that preconditioning and cold soak would be deleted. The Key Mode test should be performed using NDIR analyzers for HC, CO, and NO_x emissions and the appropriate speed and power absorption for the vehicle weight.

During the road driving and dynamometer driving, a general driveability data sheet should be filled out by the test driver giving a general description of the vehicle's performance under baseline and defect conditions. This provides data on the symptoms and detectability of the defects to the vehicle operator.

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Appendix A

CRITICALITY INDEX RANKINGS

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - EARLY MODELS

PRINCIPAL RANKING - HC

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
2. 5. 0	SPARK PLUGS	1	0.265E+02	54	0.0	59	0.0	37	0.0
2. 6. 0	IGNITION WIRES	2	0.838E+01	55	0.0	60	0.0	38	0.0
5. 1. 1	VALVE LIFTER/SPR	3	0.845E+00	3	0.845E+00	87	0.0	1	0.563E+00
5. 1. 4	VALVE SEALS	4	0.507E+00	4	0.507E+00	90	0.0	2	0.338E+00
5. 1. 5	EXHAUST VALVES	5	0.507E+00	5	0.507E+00	91	0.0	3	0.338E+00
1. 3. 4	CHOKE MECHANISM	6	0.411E+00	1	0.205E+01	41	0.0	18	0.0
1. 3. 6	POWER VALVES	7	0.411E+00	2	0.205E+01	43	0.0	20	0.0
2. 3. 2	ROTOR	8	0.231E+00	50	0.0	53	0.0	30	0.0
2. 3. 1	CAP	9	0.228E+00	49	0.0	52	0.0	29	0.0
2. 1. 0	POINTS	10	0.112E+00	47	0.0	50	0.0	27	0.0
2. 7. 0	COIL	11	0.694E-01	56	0.0	61	0.0	39	0.0
2. 9. 0	BALLAST RESISTOR	12	0.644E-01	58	0.0	63	0.0	41	0.0
5. 1. 2	VALVE CAM LOBES	13	0.507E-01	12	0.507E-01	88	0.0	5	0.338E-01
5. 1. 3	VALVE GUIDES	14	0.507E-01	13	0.507E-01	89	0.0	6	0.338E-01
5. 2. 0	PISTON RINGS	15	0.507E-01	14	0.507E-01	92	0.0	7	0.338E-01
2. 3. 5	DISTRIBUTOR DRIV	16	0.385E-01	51	0.0	56	0.0	33	0.0
6. 2. 1	EVAP CANISTER	17	0.356E-01	85	0.0	100	0.0	70	0.0
6. 3. 2	AI HOSES	18	0.275E-01	16	0.275E-01	107	0.0	77	0.0
6. 3. 7	AI PUMP/BELTS	19	0.275E-01	17	0.275E-01	112	0.0	82	0.0
6. 1. 1	PCV VALVE	20	0.266E-01	8	0.266E+00	96	0.0	66	0.0
6.10. 1	HEAT RISER	21	0.259E-01	126	0.0	125	0.0	122	0.0
1. 3.10	IDLE ADJUSTMENT	22	0.208E-01	10	0.208E+00	47	0.0	24	0.0
1. 3. 9	FLOAT AND VALVE	23	0.207E-01	6	0.414E+00	46	0.0	23	0.0
1. 3. 3	VAC BRK VALVE	24	0.205E-01	18	0.205E-01	40	0.0	17	0.0
1. 3. 5	ACCELERATOR PUMP	25	0.205E-01	19	0.205E-01	42	0.0	19	0.0

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AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - EARLY MODELS

PRINCIPAL RANKING - HC (CONT'D)

PART CODE	PART NAME	HC		CO		NOX		SMOKE	
		RANK	CI	RANK	CI	RANK	CI	RANK	CI
6. 2. 3	EVAP FRSH AIR	26	0.183E-01	87	0.0	102	0.0	72	0.0
2. 3. 7	SPARK DELAY VLV	27	0.172E-01	52	0.0	3	0.172E+00	35	0.0
3. 1. 3	TAC VAC MOTOR	28	0.169E-01	63	0.0	67	0.0	46	0.0
3. 1. 4	TAC VAC HOSES	29	0.169E-01	64	0.0	68	0.0	47	0.0
6. 1. 2	PCV HOSES	30	0.154E-01	83	0.0	97	0.0	67	0.0
6. 2. 2	EVAP HOSES	31	0.154E-01	86	0.0	101	0.0	71	0.0
1. 4. 0	FUEL FILTER	32	0.147E-01	46	0.0	49	0.0	26	0.0
3. 2. 0	AIR CLEANER ELEM	33	0.144E-01	7	0.288E+00	70	0.0	4	0.481E-01
1. 3. 1	METERING JETS	34	0.126E-01	20	0.126E-01	38	0.0	15	0.0
5. 4. 1	HEAD GASKETS	35	0.121E-01	21	0.121E-01	94	0.0	8	0.804E-02
6. 1. 3	PCV FRSHAIR FLTR	36	0.120E-01	11	0.120E+00	98	0.0	68	0.0
6. 2. 6	FUEL TANK/CAP	37	0.115E-01	90	0.0	105	0.0	75	0.0
2. 4. 0	MAG/OPT TRIGGERS	38	0.114E-01	53	0.0	58	0.0	36	0.0
1. 3. 2	METERING RODS	39	0.113E-01	9	0.227E+00	39	0.0	16	0.0
6. 2. 4	EVAP VPRLIG SEP	40	0.113E-01	88	0.0	103	0.0	73	0.0
5. 5. 0	CAMSHAFTS	41	0.694E-02	24	0.694E-02	95	0.0	9	0.462E-02
1. 3. 7	GASKETS	42	0.685E-02	43	0.0	44	0.0	21	0.0
3. 1. 1	TAC SHROUD	43	0.673E-02	61	0.0	65	0.0	44	0.0
3. 1. 2	TAC THERMOSTAT	44	0.673E-02	62	0.0	66	0.0	45	0.0
2. 2. 0	CONDENSER	45	0.657E-02	48	0.0	51	0.0	28	0.0
6. 3. 1	AI MANIFOLD	46	0.607E-02	25	0.607E-02	106	0.0	76	0.0
6. 2. 5	EVAP VAPOR CONTR	47	0.545E-02	89	0.0	104	0.0	74	0.0
2.11. 0	IGN TIMING ADJ	48	0.540E-02	60	0.0	7	0.540E-01	43	0.0
6. 5. 4	TCS CEC VALVE	49	0.425E-02	26	0.425E-02	114	0.0	98	0.0
6. 4. 8	EGR VAC AMP	50	0.359E-02	99	0.0	4	0.718E-01	90	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - EARLY MODELS

PRINCIPAL RANKING - CO

PART CODE	PART NAME	HC		CO		NOX		SMOKE	
		RANK	CI	RANK	CI	RANK	CI	RANK	CI
1. 3. 4	CHOKE MECHANISM	6	0.411E+00	1	0.205E+01	41	0.0	18	0.0
1. 3. 6	POWER VALVES	7	0.411E+00	2	0.205E+01	43	0.0	20	0.0
5. 1. 1	VALVE LIFTER/SPR	3	0.845E+00	3	0.845E+00	87	0.0	1	0.563E+00
5. 1. 4	VALVE SEALS	4	0.507E+00	4	0.507E+00	90	0.0	2	0.338E+00
5. 1. 5	EXHAUST VALVES	5	0.507E+00	5	0.507E+00	91	0.0	3	0.338E+00
1. 3. 9	FLOAT AND VALVE	23	0.207E-01	6	0.414E+00	46	0.0	23	0.0
3. 2. 0	AIR CLEANER ELEM	33	0.144E-01	7	0.788E+00	70	0.0	4	0.481E-01
6. 1. 1	PCV VALVE	20	0.266E-01	8	0.266E+00	96	0.0	66	0.0
1. 3. 2	METERING RODS	39	0.113E-01	9	0.227E+00	39	0.0	16	0.0
1. 3.10	IDLE ADJUSTMENT	22	0.208E-01	10	0.208E+00	47	0.0	24	0.0
6. 1. 3	PCV FRSHAIR FLTR	36	0.120E-01	11	0.120E+00	98	0.0	68	0.0
5. 1. 2	VALVE CAM LOBES	13	0.507E-01	12	0.507E-01	88	0.0	5	0.338E-01
5. 1. 3	VALVE GUIDES	14	0.507E-01	13	0.507E-01	89	0.0	6	0.338E-01
5. 2. 0	PISTON RINGS	15	0.507E-01	14	0.507E-01	92	0.0	7	0.338E-01
1. 2. 1	IDLE STPSOLENOID	53	0.309E-02	15	0.309E-01	35	0.0	12	0.0
6. 3. 2	AI HOSES	18	0.275E-01	16	0.275E-01	107	0.0	77	0.0
6. 3. 7	AI PUMP/BELTS	19	0.275E-01	17	0.275E-01	112	0.0	82	0.0
1. 3. 3	VAC BRK VALVE	24	0.205E-01	18	0.205E-01	40	0.0	17	0.0
1. 3. 5	ACCELERATOR PUMP	25	0.205E-01	19	0.205E-01	42	0.0	19	0.0
1. 3. 1	METERING JETS	34	0.126E-01	20	0.126E-01	38	0.0	15	0.0
5. 4. 1	HEAD GASKETS	35	0.121E-01	21	0.171E-01	94	0.0	8	0.804E-02
2. 3. 4	VACUUM ADVANCE	89	0.0	22	0.116E-01	55	0.0	32	0.0
6.10. 4	DECEL VALVE	67	0.854E-03	23	0.854E-02	128	0.0	125	0.0
5. 5. 0	CAMSHAFTS	41	0.694E-02	24	0.694E-02	95	0.0	9	0.462E-02
6. 3. 1	AI MANIFOLD	46	0.607E-02	25	0.607E-02	106	0.0	76	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - EARLY MODELS

PRINCIPAL RANKING - CO (CONT'D)

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
6. 5. 4	TCS CEC VALVE	49	0.425E-02	26	0.425E-02	114	0.0	98	0.0
2. 3. 3	MECH ADVANCE	88	0.0	27	0.385E-02	54	0.0	31	0.0
6. 3. 4	AI CHECK VALVES	51	0.333E-02	28	0.333E-02	109	0.0	79	0.0
6. 3. 3	AI AIR FILTER	54	0.278E-02	29	0.278E-02	108	0.0	78	0.0
1. 2. 2	THROTTLE DASHPOT	75	0.277E-03	30	0.277E-02	36	0.0	13	0.0
1. 2. 3	THRTTL POSITIONR	79	0.206E-03	31	0.206E-02	37	0.0	14	0.0
6. 3. 5	AI BYPASS/DVRTR	60	0.196E-02	32	0.196E-02	110	0.0	80	0.0
6.10. 3	STAGED PULLDOWN	62	0.171E-02	33	0.171E-02	127	0.0	124	0.0
6.10. 2	ELEC ASSIST CHKE	63	0.171E-02	34	0.171E-02	126	0.0	123	0.0
6. 5. 2	TCS VAC HOSES	64	0.154E-02	35	0.154E-02	113	0.0	96	0.0
2. 3. 6	DUAL DIAPHM DIST	90	0.0	36	0.143E-02	57	0.0	34	0.0
6.10. 6	DIST START SOLEN	68	0.778E-03	37	0.778E-03	129	0.0	127	0.0
6. 7. 2	OSAC VAC HOSES	70	0.426E-03	38	0.426E-03	118	0.0	109	0.0
6. 8. 2	ESC HOSES	80	0.200E-03	39	0.200E-03	120	0.0	114	0.0
6. 6. 2	SCS VACUM LINE	82	0.120E-03	40	0.120E-03	116	0.0	104	0.0
1. 1. 1	NEW CARB	84	0.0	41	0.0	33	0.0	10	0.0
1. 1. 2	REBUILT CARB	85	0.0	42	0.0	34	0.0	11	0.0
1. 3. 7	GASKETS	42	0.685E-02	43	0.0	44	0.0	21	0.0
1. 3. 8	REBUILDING KITS	86	0.0	44	0.0	45	0.0	22	0.0
1. 3.11	IDLE ENRICHMENT	87	0.0	45	0.0	48	0.0	25	0.0
1. 4. 0	FUEL FILTER	32	0.147E-01	46	0.0	49	0.0	26	0.0
2. 1. 0	POINTS	10	0.112E+00	47	0.0	50	0.0	27	0.0
2. 2. 0	CONDENSER	45	0.657E-02	48	0.0	51	0.0	28	0.0
2. 3. 1	CAP	9	0.228E+00	49	0.0	52	0.0	29	0.0
2. 3. 2	ROTOR	8	0.231E+00	50	0.0	53	0.0	30	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - EARLY MODELS

PRINCIPAL RANKING - NOX

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
6. 4. 1	EGR VALVES	113	0.0	92	0.0	1	0.517E+00	83	0.0
6. 4. 3	EGR THERMO VALVE	114	0.0	94	0.0	2	0.204E+00	85	0.0
2. 3. 7	SPARK DELAY VLV	27	0.172E-01	52	0.0	3	0.172E+00	35	0.0
6. 4. 8	EGR VAC AMP	50	0.359E-02	99	0.0	4	0.718E-01	90	0.0
6. 5. 8	TCS TEMP SWITCH	52	0.327E-02	109	0.0	5	0.654E-01	102	0.0
6. 5. 6	TCS TRANS SWITCH	55	0.278E-02	107	0.0	6	0.555E-01	100	0.0
2.11. 0	IGN TIMING ADJ	48	0.540E-02	60	0.0	7	0.540E-01	43	0.0
6. 5. 1	TCS VAC SOLENOID	56	0.260E-02	104	0.0	8	0.520E-01	95	0.0
6. 4. 2	EGR HOSES/SEALS	57	0.251E-02	93	0.0	9	0.502E-01	84	0.0
6.10. 7	THERMO VAC VALV	59	0.217E-02	128	0.0	10	0.435E-01	128	0.0
6. 4. 4	EGR SOLENOID VLV	115	0.0	95	0.0	11	0.425E-01	86	0.0
6. 5. 3	TCS TIME DELAY	61	0.183E-02	105	0.0	12	0.365E-01	97	0.0
6. 4. 5	EGR TEMP SWITCH	116	0.0	96	0.0	13	0.234E-01	87	0.0
6. 7. 1	OSAC VAC ORIFICE	58	0.230E-02	114	0.0	14	0.230E-01	108	0.0
6. 5. 5	TCS THERMO VALVE	66	0.109E-02	106	0.0	15	0.219E-01	99	0.0
6. 4. 7	EGR TIME DELAY	118	0.0	98	0.0	16	0.188E-01	89	0.0
6. 4.10	EGR CARB SPACER	120	0.0	101	0.0	17	0.144E-01	92	0.0
6. 4.11	EGR BACKPRES SEN	121	0.0	102	0.0	18	0.143E-01	93	0.0
6. 7. 4	OSAC VAC BYPASS	65	0.130E-02	116	0.0	19	0.130E-01	111	0.0
6. 4. 6	EGR SPEED/TRANS	117	0.0	97	0.0	20	0.878E-02	88	0.0
6. 8. 1	ESC ELEC MODULE	71	0.360E-03	118	0.0	21	0.719E-02	113	0.0
6. 8. 3	ESC VAC VALVES	72	0.360E-03	119	0.0	22	0.719E-02	115	0.0
6. 8. 4	ESC TEMP SWITCH	73	0.360E-03	120	0.0	23	0.719E-02	116	0.0
6. 8. 5	ESC SPEED SWITCH	74	0.360E-03	121	0.0	24	0.719E-02	117	0.0
6.10. 5	DIST VACDECL VLV	76	0.254E-03	127	0.0	25	0.508E-02	126	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - EARLY MODELS

PRINCIPAL RANKING - NOX (CONT'D)

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
6. 7. 5	OSAC TEMP SENSOR	69	0.432E-03	117	0.0	26	0.432E-02	112	0.0
6. 6. 1	SCS VACUUM SOLEN	77	0.216E-03	110	0.0	27	0.432E-02	103	0.0
6. 6. 4	SCS SPEED SWITCH	78	0.216E-03	112	0.0	28	0.432E-02	106	0.0
6. 6. 5	SCS THERMO VALVE	81	0.189E-03	113	0.0	29	0.378E-02	107	0.0
6. 4. 9	EGR VAC REDUCER	119	0.0	100	0.0	30	0.181E-02	91	0.0
6. 4.12	EGR CHECK VALVE	122	0.0	103	0.0	31	0.316E-03	94	0.0
8. 1. 0	DISTR VACUUM VLV	83	0.430E-04	133	0.0	32	0.430E-04	133	0.0
1. 1. 1	NEW CARB	84	0.0	41	0.0	33	0.0	10	0.0
1. 1. 2	REBUILT CARB	85	0.0	42	0.0	34	0.0	11	0.0
1. 2. 1	IDLE STPSOLENOID	53	0.309E-02	15	0.309E-01	35	0.0	12	0.0
1. 2. 2	THROTTLE DASHPOT	75	0.277E-03	30	0.277E-02	36	0.0	13	0.0
1. 2. 3	THRTTL POSITIONR	79	0.206E-03	31	0.206E-02	37	0.0	14	0.0
1. 3. 1	METERING JETS	34	0.126E-01	20	0.126E-01	38	0.0	15	0.0
1. 3. 2	METERING RODS	39	0.113E-01	9	0.227E+00	39	0.0	16	0.0
1. 3. 3	VAC BRK VALVE	24	0.205E-01	18	0.205E-01	40	0.0	17	0.0
1. 3. 4	CHOKE MECHANISM	6	0.411E+00	1	0.205E+01	41	0.0	18	0.0
1. 3. 5	ACCELERATOR PUMP	25	0.205E-01	19	0.205E-01	42	0.0	19	0.0
1. 3. 6	POWER VALVES	7	0.411E+00	2	0.205E+01	43	0.0	20	0.0
1. 3. 7	GASKETS	42	0.685E-02	43	0.0	44	0.0	21	0.0
1. 3. 8	REBUILDING KITS	86	0.0	44	0.0	45	0.0	22	0.0
1. 3. 9	FLOAT AND VALVE	23	0.207E-01	6	0.414E+00	46	0.0	23	0.0
1. 3.10	IDLE ADJUSTMENT	22	0.208E-01	10	0.208E+00	47	0.0	24	0.0
1. 3.11	IDLE ENRICHMENT	87	0.0	45	0.0	48	0.0	25	0.0
1. 4. 0	FUEL FILTER	32	0.147E-01	46	0.0	49	0.0	26	0.0
2. 1. 0	POINTS	10	0.112E+00	47	0.0	50	0.0	27	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - EARLY MODELS

PRINCIPAL RANKING - SMOKE

PART CODE	PART NAME	HC		CO		NOX		SMOKE	
		RANK	CI	RANK	CI	RANK	CI	RANK	CI
5. 1. 1	VALVE LIFTER/SPR	3	0.845E+00	3	0.845E+00	87	0.0	1	0.563E+00
5. 1. 4	VALVE SEALS	4	0.507E+00	4	0.507E+00	90	0.0	2	0.338E+00
5. 1. 5	EXHAUST VALVES	5	0.507E+00	5	0.507E+00	91	0.0	3	0.338E+00
3. 2. 0	AIR CLEANER ELEM	33	0.144E-01	7	0.288E+00	70	0.0	4	0.481E-01
5. 1. 2	VALVE CAM LOBES	13	0.507E-01	12	0.507E-01	88	0.0	5	0.338E-01
5. 1. 3	VALVE GUIDES	14	0.507E-01	13	0.507E-01	89	0.0	6	0.338E-01
5. 2. 0	PISTON RINGS	15	0.507E-01	14	0.507E-01	92	0.0	7	0.338E-01
5. 4. 1	HEAD GASKETS	35	0.121E-01	21	0.121E-01	94	0.0	8	0.804E-02
5. 5. 0	CAMSHAFTS	41	0.694E-02	24	0.694E-02	95	0.0	9	0.462E-02
1. 1. 1	NEW CARB	84	0.0	41	0.0	33	0.0	10	0.0
1. 1. 2	REBUILT CARB	85	0.0	42	0.0	34	0.0	11	0.0
1. 2. 1	IDLE STPSOLENOID	53	0.309E-02	15	0.309E-01	35	0.0	12	0.0
1. 2. 2	THRUTTLE DASHPOT	75	0.277E-03	30	0.277E-02	36	0.0	13	0.0
1. 2. 3	THRTTL POSITIONR	79	0.206E-03	31	0.206E-02	37	0.0	14	0.0
1. 3. 1	METERING JETS	34	0.126E-01	20	0.126E-01	38	0.0	15	0.0
1. 3. 2	METERING RODS	39	0.113E-01	9	0.227E+00	39	0.0	16	0.0
1. 3. 3	VAC BRK VALVE	24	0.205E-01	18	0.205E-01	40	0.0	17	0.0
1. 3. 4	CHOKE MECHANISM	6	0.411E+00	1	0.205E+01	41	0.0	18	0.0
1. 3. 5	ACCELERATOR PUMP	25	0.205E-01	19	0.205E-01	42	0.0	19	0.0
1. 3. 6	POWER VALVES	7	0.411E+00	2	0.205E+01	43	0.0	20	0.0
1. 3. 7	GASKETS	42	0.685E-02	43	0.0	44	0.0	21	0.0
1. 3. 8	REBUILDING KITS	86	0.0	44	0.0	45	0.0	22	0.0
1. 3. 9	FLOAT AND VALVE	23	0.207E-01	6	0.414E+00	46	0.0	23	0.0
1. 3.10	IDLE ADJUSTMENT	22	0.208E-01	10	0.208E+00	47	0.0	24	0.0
1. 3.11	IDLE ENRICHMENT	87	0.0	45	0.0	48	0.0	25	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - EARLY MODELS

PRINCIPAL RANKING - SMOKE (CONT'D)

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
1. 4. 0	FUEL FILTER	32	0.147E-01	46	0.0	49	0.0	26	0.0
2. 1. 0	POINTS	10	0.112E+00	47	0.0	50	0.0	27	0.0
2. 2. 0	CONDENSER	45	0.657E-02	48	0.0	51	0.0	28	0.0
2. 3. 1	CAP	9	0.228E+00	49	0.0	52	0.0	29	0.0
2. 3. 2	ROTOR	8	0.231E+00	50	0.0	53	0.0	30	0.0
2. 3. 3	MECH ADVANCE	88	0.0	27	0.385E-02	54	0.0	31	0.0
2. 3. 4	VACUUM ADVANCE	89	0.0	22	0.116E-01	55	0.0	32	0.0
2. 3. 5	DISTRIBUTOR DRIV	16	0.385E-01	51	0.0	56	0.0	33	0.0
2. 3. 6	DUAL DIAPHM DIST	90	0.0	36	0.143E-02	57	0.0	34	0.0
2. 3. 7	SPARK DELAY VLV	27	0.172E-01	52	0.0	3	0.17[illegible]E+00	35	0.0
2. 4. 0	MAG/OPT TRIGGERS	38	0.114E-01	53	0.0	58	0.0	36	0.0
2. 5. 0	SPARK PLUGS	1	0.265E+02	54	0.0	59	0.0	37	0.0
2. 6. 0	IGNITION WIRES	2	0.838E+01	55	0.0	60	0.0	38	0.0
2. 7. 0	COIL	11	0.694E-01	56	0.0	61	0.0	39	0.0
2. 8. 0	CAPACITIVE DISCH	91	0.0	57	0.0	62	0.0	40	0.0
2. 9. 0	BALLAST RESISTOR	12	0.694E-01	58	0.0	63	0.0	41	0.0
2.10. 0	EI CONTROL CIRCT	92	0.0	59	0.0	64	0.0	42	0.0
2.11. 0	IGN TIMING ADJ	48	0.540E-02	60	0.0	7	0.540E-01	43	0.0
3. 1. 1	TAC SHROUD	43	0.673E-02	61	0.0	65	0.0	44	0.0
3. 1. 2	TAC THERMOSTAT	44	0.673E-02	62	0.0	66	0.0	45	0.0
3. 1. 3	TAC VAC MOTOR	28	0.169E-01	63	0.0	67	0.0	46	0.0
3. 1. 4	TAC VAC HOSES	29	0.169E-01	64	0.0	68	0.0	47	0.0
3. 1. 5	TAC FRESH AIR IN	93	0.0	65	0.0	69	0.0	48	0.0
3. 3. 0	INTAKE MANIFOLD	94	0.0	66	0.0	71	0.0	49	0.0
3. 4. 0	TURBOCHARGER	95	0.0	67	0.0	72	0.0	50	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - LATE MODELS

PRINCIPAL RANKING - HC

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
2. 5. 0	SPARK PLUGS	1	0.348E+01	12	0.348E-01	52	0.0	42	0.0
2. 6. 0	IGNITION WIRES	2	0.237E+01	16	0.237E-01	53	0.0	43	0.0
6. 9. 2	CAT ACTIVE MEDIA	3	0.190E+00	3	0.190E+00	120	0.0	119	0.0
1. 3. 4	CHOKE MECHANISM	4	0.120E+00	1	0.602E+00	34	0.0	23	0.0
1. 3. 6	POWER VALVES	5	0.120E+00	2	0.602E+00	36	0.0	25	0.0
6.10. 1	HEAT RISER	6	0.117E+00	21	0.117E-01	123	0.0	122	0.0
6. 2. 1	EVAP CANISTER	7	0.112E+00	86	0.0	92	0.0	70	0.0
2. 3. 1	CAP	8	0.670E-01	35	0.335E-02	45	0.0	34	0.0
2. 3. 2	ROTOR	9	0.670E-01	36	0.335E-02	46	0.0	35	0.0
1. 3.10	IDLE ADJUSTMENT	10	0.602E-01	7	0.602E-01	40	0.0	29	0.0
3. 1. 3	TAC VAC MOTOR	11	0.557E-01	30	0.557E-02	60	0.0	51	0.0
3. 1. 4	TAC VAC HOSES	12	0.555E-01	31	0.555E-02	61	0.0	52	0.0
6. 1. 3	PCV FRSHAIR FLTR	13	0.506E-01	8	0.506E-01	90	0.0	68	0.0
6. 1. 1	PCV VALVE	14	0.427E-01	10	0.427E-01	88	0.0	66	0.0
6. 1. 2	PCV HOSES	15	0.383E-01	50	0.112E-02	89	0.0	67	0.0
6. 2. 2	EVAP HOSES	16	0.383E-01	51	0.112E-02	93	0.0	71	0.0
5. 1. 1	VALVE LIFTER/SPR	17	0.280E-01	15	0.280E-01	79	0.0	1	0.280E+00
3. 1. 1	TAC SHROUD	18	0.201E-01	73	0.0	58	0.0	49	0.0
3. 1. 2	TAC THERMOSTAT	19	0.201E-01	74	0.0	59	0.0	50	0.0
2. 4. 0	MAG/OPT TRIGGERS	20	0.198E-01	58	0.198E-03	51	0.0	41	0.0
6. 2. 3	EVAP FRSH AIR	21	0.174E-01	87	0.0	94	0.0	72	0.0
6. 3. 7	AI PUMP/BELTS	22	0.158E-01	17	0.158E-01	104	0.0	82	0.0
6. 3. 2	AI HOSES	23	0.158E-01	11	0.395E-01	99	0.0	77	0.0
5. 1. 4	VALVE SEALS	24	0.146E-01	18	0.146E-01	82	0.0	2	0.146E+00
5. 1. 5	EXHAUST VALVES	25	0.146E-01	19	0.146E-01	83	0.0	3	0.146E+00

CRITICALITY INDEX RANKING - LATE MODELS

PRINCIPAL RANKING - HC (CONT'D)

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
6. 2. 6	FUEL TANK/CAP	26	0.134E-01	90	0.0	97	0.0	75	0.0
6. 2. 4	EVAP VPRLIG SEP	27	0.125E-01	88	0.0	95	0.0	73	0.0
6. 3. 5	AI BYPASS/DVRTR	28	0.113E-01	14	0.283E-01	102	0.0	80	0.0
6. 3. 4	AI CHECK VALVES	29	0.827E-02	25	0.827E-02	101	0.0	79	0.0
6. 2. 5	EVAP VAPOR CONTR	30	0.803E-02	89	0.0	96	0.0	74	0.0
6. 3. 3	AI AIR FILTER	31	0.792E-02	26	0.792E-02	100	0.0	78	0.0
1. 3. 2	METERING RODS	32	0.716E-02	4	0.143E+00	32	0.0	21	0.0
1. 3. 3	VAC BRK VALVE	33	0.653E-02	6	0.653E-01	33	0.0	22	0.0
1. 2. 1	IDLE STPSOLENOID	34	0.630E-02	28	0.630E-02	28	0.0	17	0.0
1. 3. 5	ACCELERATOR PUMP	35	0.623E-02	29	0.623E-02	35	0.0	24	0.0
1. 3. 9	FLOAT AND VALVE	36	0.602E-02	5	0.120E+00	39	0.0	28	0.0
1. 4. 0	FUEL FILTER	37	0.431E-02	32	0.431E-02	42	0.0	31	0.0
1. 3. 1	METERING JETS	38	0.371E-02	34	0.371E-02	31	0.0	20	0.0
6. 3. 1	AI MANIFOLD	39	0.335E-02	24	0.837E-02	98	0.0	76	0.0
6.10. 7	THERMO VAC VALV	40	0.327E-02	128	0.0	3	0.654E-01	128	0.0
2. 3. 7	SPARK DELAY VLV	41	0.299E-02	69	0.0	5	0.299E-01	40	0.0
4.12. 0	FI STARTING VALV	42	0.284E-02	20	0.142E-01	77	0.0	64	0.0
4.13. 0	FI IDLE ADJUST	43	0.283E-02	37	0.283E-02	78	0.0	10	0.378E-02
6.10. 4	DECEL VALVE	44	0.278E-02	38	0.278E-02	126	0.0	125	0.0
1. 3.11	IDLE ENRICHMENT	45	0.261E-02	39	0.261E-02	41	0.0	30	0.0
3. 2. 0	AIR CLEANER ELEM	46	0.233E-02	9	0.466E-01	63	0.0	5	0.155E-01
6. 4. 8	EGR VAC AMP	47	0.229E-02	99	0.0	4	0.458E-01	90	0.0
2. 7. 0	COIL	48	0.201E-02	40	0.201E-02	54	0.0	44	0.0
1. 3. 7	GASKETS	49	0.201E-02	41	0.201E-02	37	0.0	26	0.0
2. 9. 0	BALLAST RESISTOR	50	0.200E-02	42	0.200E-02	56	0.0	46	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - LATE MODELS

PRINCIPAL RANKING - CO

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
1. 3. 4	CHOKE MECHANISM	4	0.120E+00	1	0.602E+00	34	0.0	23	0.0
1. 3. 6	POWER VALVES	5	0.120E+00	2	0.602E+00	36	0.0	25	0.0
6. 9. 2	CAT ACTIVE MEDIA	3	0.190E+00	3	0.190E+00	120	0.0	119	0.0
1. 3. 2	METERING RODS	32	0.716E-02	4	0.143E+00	32	0.0	21	0.0
1. 3. 9	FLOAT AND VALVE	36	0.602E-02	5	0.120E+00	39	0.0	28	0.0
1. 3. 3	VAC BRK VALVE	33	0.653E-02	6	0.653E-01	33	0.0	22	0.0
1. 3.10	IDLE ADJUSTMENT	10	0.602E-01	7	0.602E-01	40	0.0	29	0.0
6. 1. 3	PCV FRSHAIR FLTR	13	0.506E-01	8	0.506E-01	90	0.0	68	0.0
3. 2. 0	AIR CLEANER ELEM	46	0.233E-02	9	0.466E-01	63	0.0	5	0.155E-01
6. 1. 1	PCV VALVE	14	0.427E-01	10	0.427E-01	88	0.0	66	0.0
6. 3. 2	AI HOSES	23	0.158E-01	11	0.395E-01	99	0.0	77	0.0
2. 5. 0	SPARK PLUGS	1	0.348E+01	12	0.348E-01	52	0.0	42	0.0
2. 3. 4	VACUUM ADVANCE	90	0.0	13	0.335E-01	48	0.0	37	0.0
6. 3. 5	AI BYPASS/DVRTR	28	0.113E-01	14	0.283E-01	102	0.0	80	0.0
5. 1. 1	VALVE LIFTER/SPR	17	0.280E-01	15	0.280E-01	79	0.0	1	0.280E+00
2. 6. 0	IGNITION WIRES	2	0.237E+01	16	0.237E-01	53	0.0	43	0.0
6. 3. 7	AI PUMP/BELTS	22	0.158E-01	17	0.158E-01	104	0.0	82	0.0
5. 1. 4	VALVE SEALS	24	0.146E-01	18	0.146E-01	82	0.0	2	0.146E+00
5. 1. 5	EXHAUST VALVES	25	0.146E-01	19	0.146E-01	83	0.0	3	0.146E+00
4.12. 0	FI STARTING VALV	42	0.284E-02	20	0.142E-01	77	0.0	64	0.0
6.10. 1	HEAT RISER	6	0.117E+00	21	0.117E-01	123	0.0	122	0.0
2. 3. 3	MECH ADVANCE	89	0.0	22	0.112E-01	47	0.0	36	0.0
6.10. 2	ELEC ASSIST CHKE	57	0.904E-03	23	0.904E-02	124	0.0	123	0.0
6. 3. 1	AI MANIFOLD	39	0.335E-02	24	0.837E-02	98	0.0	76	0.0
6. 3. 4	AI CHECK VALVES	29	0.827E-02	25	0.827E-03	101	0.0	79	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - LATE MODELS

PRINCIPAL RANKING - CO (CONT'D)

PART CODE	PART NAME	HC		CO		NOX		SMOKE	
		RANK	CI	RANK	CI	RANK	CI	RANK	CI
6. 3. 3	AI AIR FILTER	31	0.792E-02	26	0.792E-02	100	0.0	78	0.0
4. 9. 0	EFI INJECTORS	61	0.360E-03	27	0.719E-02	75	0.0	61	0.0
1. 2. 1	IDLE STPSOLENOID	34	0.630E-02	28	0.630E-02	28	0.0	17	0.0
1. 3. 5	ACCELERATOR PUMP	35	0.623E-02	29	0.623E-02	35	0.0	24	0.0
3. 1. 3	TAC VAC MOTOR	11	0.557E-01	30	0.557E-02	60	0.0	51	0.0
3. 1. 4	TAC VAC HOSES	12	0.555E-01	31	0.555E-02	61	0.0	52	0.0
1. 4. 0	FUEL FILTER	37	0.431E-02	32	0.431E-02	42	0.0	31	0.0
1. 2. 2	THROTTLE DASHPOT	59	0.396E-03	33	0.396E-02	29	0.0	18	0.0
1. 3. 1	METERING JETS	38	0.371E-02	34	0.371E-02	31	0.0	20	0.0
2. 3. 1	CAP	8	0.670E-01	35	0.335E-02	45	0.0	34	0.0
2. 3. 2	ROTOR	9	0.670E-01	36	0.335E-02	46	0.0	35	0.0
4.13. 0	FI IDLE ADJUST	43	0.283E-02	37	0.283E-02	78	0.0	10	0.378E-02
6.10. 4	DECEL VALVE	44	0.278E-02	38	0.278E-02	126	0.0	125	0.0
1. 3.11	IDLE ENRICHMENT	45	0.261E-02	39	0.261E-02	41	0.0	30	0.0
2. 7. 0	COIL	48	0.201E-02	40	0.201E-02	54	0.0	44	0.0
1. 3. 7	GASKETS	49	0.201E-02	41	0.201E-02	37	0.0	26	0.0
2. 9. 0	BALLAST RESISTOR	50	0.200E-02	42	0.200E-02	56	0.0	46	0.0
4. 3. 0	FI PRES SENS/REG	73	0.170E-03	43	0.170E-02	69	0.0	13	0.119E-02
1. 2. 3	THRTTL POSITIONR	74	0.170E-03	44	0.170E-02	30	0.0	19	0.0
5. 1. 2	VALVE CAM LOBES	52	0.146E-02	45	0.146E-02	80	0.0	6	0.146E-01
5. 1. 3	VALVE GUIDES	53	0.146E-02	46	0.146E-02	81	0.0	7	0.146E-01
5. 2. 0	PISTON RINGS	54	0.146E-02	47	0.146E-02	84	0.0	8	0.146E-01
6. 7. 2	OSAC VAC HOSES	75	0.145E-03	48	0.145E-02	112	0.0	109	0.0
4. 7. 0	EFI TEMPSENS/SWH	64	0.246E-03	49	0.123E-02	73	0.0	59	0.0
6. 1. 2	PCV HOSES	15	0.383E-01	50	0.112E-02	89	0.0	67	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - LATE MODELS

PRINCIPAL RANKING - NOX

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
6. 4. 1	EGR VALVES	106	0.0	92	0.0	1	0.212E+00	83	0.0
6. 4. 3	EGR THERMO VALVE	107	0.0	94	0.0	2	0.132E+00	85	0.0
6.10. 7	THERMO VAC VALV	40	0.327E-02	128	0.0	3	0.654E-01	128	0.0
6. 4. 8	EGR VAC AMP	47	0.229E-02	99	0.0	4	0.458E-01	90	0.0
2. 3. 7	SPARK DELAY VLV	41	0.299E-02	69	0.0	5	0.299E-01	40	0.0
6. 4. 2	EGR HOSES/SEALS	56	0.108E-02	93	0.0	6	0.216E-01	84	0.0
2.11. 0	IGN TIMING ADJ	51	0.156E-02	72	0.0	7	0.156E-01	48	0.0
6. 4.10	EGR CARB SPACER	113	0.0	101	0.0	8	0.153E-01	92	0.0
6. 4.11	EGR BACKPRES SEN	114	0.0	102	0.0	9	0.149E-01	93	0.0
6. 4. 6	EGR SPEED/TRANS	110	0.0	97	0.0	10	0.102E-01	88	0.0
6. 7. 1	OSAC VAC ORIFICE	58	0.784E-03	115	0.0	11	0.784E-02	108	0.0
6. 4. 4	EGR SOLENOID VLV	108	0.0	95	0.0	12	0.538E-02	86	0.0
6. 4. 7	EGR TIME DELAY	111	0.0	98	0.0	13	0.523E-02	89	0.0
6. 8. 5	ESC SPEED SWITCH	63	0.261E-03	123	0.0	14	0.523E-02	117	0.0
6. 5. 8	TCS TEMP SWITCH	55	0.209E-03	110	0.0	15	0.418E-02	102	0.0
6. 5. 1	TCS VAC SOLENOID	68	0.192E-03	104	0.0	16	0.385E-02	95	0.0
6. 5. 6	TCS TRANS SWITCH	69	0.192E-03	108	0.0	17	0.385E-02	100	0.0
6. 5. 5	TCS THERMO VALVE	71	0.189E-03	107	0.0	18	0.377E-02	99	0.0
6. 8. 1	ESC ELEC MODULE	77	0.712E-04	119	0.0	19	0.142E-02	113	0.0
6. 5. 3	TCS TIME DELAY	78	0.592E-04	105	0.0	20	0.118E-02	97	0.0
6. 6. 5	SCS THERMO VALVE	80	0.226E-04	114	0.0	21	0.451E-03	107	0.0
6. 4. 5	EGR TEMP SWITCH	109	0.0	96	0.0	22	0.150E-03	87	0.0
6. 6. 1	SCS VACUUM SOLEN	83	0.752E-05	111	0.0	23	0.150E-03	103	0.0
6. 6. 4	SCS SPEED SWITCH	84	0.752E-05	113	0.0	24	0.150E-03	106	0.0
4.10. 0	EFI TRIGGER SWCH	79	0.273E-04	65	0.137E-04	25	0.137E-05	62	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - LATE MODELS

PRINCIPAL RANKING - NOX (CONT'D)

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
1. 1. 1	NEW CARB	86	0.0	66	0.0	26	0.0	15	0.0
1. 1. 2	REBUILT CARB	87	0.0	67	0.0	27	0.0	16	0.0
1. 2. 1	IDLE STPSOLENOID	34	0.630E-02	28	0.630E-02	28	0.0	17	0.0
1. 2. 2	THROTTLE DASHPOT	59	0.396E-03	33	0.396E-02	29	0.0	18	0.0
1. 2. 3	THRTTL POSITIONR	74	0.170E-03	44	0.170E-02	30	0.0	19	0.0
1. 3. 1	METERING JETS	38	0.371E-02	34	0.371E-02	31	0.0	20	0.0
1. 3. 2	METERING RODS	32	0.716E-02	4	0.143E+00	32	0.0	21	0.0
1. 3. 3	VAC BRK VALVE	33	0.653E-02	6	0.653E-01	33	0.0	22	0.0
1. 3. 4	CHOKE MECHANISM	4	0.120E+00	1	0.602E+00	34	0.0	23	0.0
1. 3. 5	ACCELERATOR PUMP	35	0.623E-02	29	0.623E-02	35	0.0	24	0.0
1. 3. 6	POWER VALVES	5	0.120E+00	2	0.602E+00	36	0.0	25	0.0
1. 3. 7	GASKETS	49	0.201E-02	41	0.201E-02	37	0.0	26	0.0
1. 3. 8	REBUILDING KITS	88	0.0	68	0.0	38	0.0	27	0.0
1. 3. 9	FLOAT AND VALVE	36	0.602E-02	5	0.120E+00	39	0.0	28	0.0
1. 3.10	IDLE ADJUSTMENT	10	0.602E-01	7	0.602E-01	40	0.0	29	0.0
1. 3.11	IDLE ENRICHMENT	45	0.261E-02	39	0.261E-02	41	0.0	30	0.0
1. 4. 0	FUEL FILTER	37	0.431E-02	32	0.431E-02	42	0.0	31	0.0
2. 1. 0	POINTS	60	0.393E-03	55	0.393E-03	43	0.0	32	0.0
2. 2. 0	CONDENSER	81	0.168E-04	64	0.168E-04	44	0.0	33	0.0
2. 3. 1	CAP	8	0.670E-01	35	0.335E-02	45	0.0	34	0.0
2. 3. 2	ROTOR	9	0.670E-01	36	0.335E-02	46	0.0	35	0.0
2. 3. 3	MECH ADVANCE	89	0.0	22	0.112E-01	47	0.0	36	0.0
2. 3. 4	VACUUM ADVANCE	90	0.0	13	0.335E-01	48	0.0	37	0.0
2. 3. 5	DISTRIBUTOR DRIV	55	0.111E-02	52	0.111E-02	49	0.0	38	0.0
2. 3. 6	DUAL DIAPHM DIST	91	0.0	54	0.692E-03	50	0.0	39	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - LATE MODELS

PRINCIPAL RANKING - SMOKE

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
5. 1. 1	VALVE LIFTER/SPR	17	0.280E-01	15	0.280E-01	79	0.0	1	0.280E+00
5. 1. 4	VALVE SEALS	24	0.146E-01	18	0.146E-01	82	0.0	2	0.146E+00
5. 1. 5	EXHAUST VALVES	25	0.146E-01	19	0.146E-01	83	0.0	3	0.146E+00
4. 5. 0	MFI VALVES	100	0.0	81	0.0	71	0.0	4	0.708E-01
3. 2. 0	AIR CLEANER ELEM	46	0.233E-02	9	0.466E-01	63	0.0	5	0.155E-01
5. 1. 2	VALVE CAM LUBES	52	0.146E-02	45	0.146E-02	80	0.0	6	0.146E-01
5. 1. 3	VALVE GUIDES	53	0.146E-02	46	0.146E-02	81	0.0	7	0.146E-01
5. 2. 0	PISTON RINGS	54	0.146E-02	47	0.146E-02	84	0.0	8	0.146E-01
4. 4. 0	FI THROTTLE VALV	99	0.0	80	0.0	70	0.0	9	0.388E-02
4.13. 0	FI IDLE ADJUST	43	0.283E-02	37	0.283E-02	78	0.0	10	0.378E-02
5. 4. 1	HEAD GASKETS	62	0.349E-03	56	0.349E-03	86	0.0	11	0.349E-02
5. 5. 0	CAMSHAFTS	66	0.207E-03	57	0.207E-03	87	0.0	12	0.207E-02
4. 3. 0	FI PRES SENS/REG	73	0.170E-03	43	0.170E-02	69	0.0	13	0.119E-02
3. 4. 0	TURBOCHARGER	95	0.0	76	0.0	65	0.0	14	0.468E-04
1. 1. 1	NEW CARB	86	0.0	66	0.0	26	0.0	15	0.0
1. 1. 2	REBUILT CARB	87	0.0	67	0.0	27	0.0	16	0.0
1. 2. 1	IDLE STPSOLENOID	34	0.630E-02	28	0.630E-02	28	0.0	17	0.0
1. 2. 2	THROTTLE DASHPOT	59	0.396E-03	33	0.396E-02	29	0.0	18	0.0
1. 2. 3	THRTTL POSITIONR	74	0.170E-03	44	0.170E-02	30	0.0	19	0.0
1. 3. 1	METERING JETS	38	0.371E-02	34	0.371E-02	31	0.0	20	0.0
1. 3. 2	METERING RODS	32	0.716E-02	4	0.143E+00	32	0.0	21	0.0
1. 3. 3	VAC BRK VALVE	33	0.653E-02	6	0.653E-01	33	0.0	22	0.0
1. 3. 4	CHOKE MECHANISM	4	0.120E+00	1	0.602E+00	34	0.0	23	0.0
1. 3. 5	ACCELERATOR PUMP	35	0.623E-02	29	0.623E-02	35	0.0	24	0.0
1. 3. 6	POWER VALVES	5	0.120E+00	2	0.602E+00	36	0.0	25	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - LATE MODELS

PRINCIPAL RANKING - SMOKE (CONT'D)

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
1. 3. 7	GASKETS	49	0.201E-02	41	0.201E-02	37	0.0	26	0.0
1. 3. 8	REBUILDING KITS	88	0.0	68	0.0	38	0.0	27	0.0
1. 3. 9	FLOAT AND VALVE	36	0.602E-02	5	0.120E+00	39	0.0	28	0.0
1. 3.10	IDLE ADJUSTMENT	10	0.602E-01	7	0.602E-01	40	0.0	29	0.0
1. 3.11	IDLE ENRICHMENT	45	0.261E-02	39	0.261E-02	41	0.0	30	0.0
1. 4. 0	FUEL FILTER	37	0.431E-02	32	0.431E-02	42	0.0	31	0.0
2. 1. 0	POINTS	60	0.393E-03	55	0.393E-03	43	0.0	32	0.0
2. 2. 0	CONDENSER	81	0.168E-04	64	0.168E-04	44	0.0	33	0.0
2. 3. 1	CAP	8	0.670E-01	35	0.335E-02	45	0.0	34	0.0
2. 3. 2	ROTOR	9	0.670E-01	36	0.335E-02	46	0.0	35	0.0
2. 3. 3	MECH ADVANCE	89	0.0	22	0.112E-01	47	0.0	36	0.0
2. 3. 4	VACUUM ADVANCE	90	0.0	13	0.335E-01	48	0.0	37	0.0
2. 3. 5	DISTRIBUTOR DRIV	55	0.111E-02	52	0.111E-02	49	0.0	38	0.0
2. 3. 6	DUAL DIAPHM DIST	91	0.0	54	0.692E-03	50	0.0	39	0.0
2. 3. 7	SPARK DELAY VLV	41	0.299E-02	69	0.0	5	0.299E-01	40	0.0
2. 4. 0	MAG/OPT TRIGGERS	20	0.198E-01	58	0.198E-03	51	0.0	41	0.0
2. 5. 0	SPARK PLUGS	1	0.348E+01	12	0.348E-01	52	0.0	42	0.0
2. 6. 0	IGNITION WIRES	2	0.237E+01	16	0.237E-01	53	0.0	43	0.0
2. 7. 0	COIL	48	0.201E-02	40	0.201E-02	54	0.0	44	0.0
2. 8. 0	CAPACITIVE DISCH	92	0.0	70	0.0	55	0.0	45	0.0
2. 9. 0	BALLAST RESISTOR	50	0.200E-02	42	0.200E-02	56	0.0	46	0.0
2.10. 0	EI CONTROL CIRCT	93	0.0	71	0.0	57	0.0	47	0.0
2.11. 0	IGN TIMING ADJ	51	0.156E-02	72	0.0	7	0.156E-01	48	0.0
3. 1. 1	TAC SHROUD	18	0.201E-01	73	0.0	58	0.0	49	0.0
3. 1. 2	TAC THERMOSTAT	19	0.201E-01	74	0.0	59	0.0	50	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - ALL MODELS

PRINCIPAL RANKING - HC

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
2. 5. 0	SPARK PLUGS	1	0.300E+02	21	0.348E-01	60	0.0	42	0.0
2. 6. 0	IGNITION WIRES	2	0.107E+02	24	0.237E-01	61	0.0	43	0.0
5. 1. 1	VALVE LIFTER/SPR	3	0.873E+00	3	0.873E+00	87	0.0	2	0.211E+00
1. 3. 4	CHOKE MECHANISM	4	0.531E+00	1	0.266E+01	42	0.0	23	0.0
1. 3. 6	POWER VALVES	5	0.531E+00	2	0.266E+01	44	0.0	25	0.0
5. 1. 4	VALVE SEALS	6	0.521E+00	5	0.521E+00	90	0.0	5	0.126E+00
5. 1. 5	EXHAUST VALVES	7	0.521E+00	6	0.521E+00	91	0.0	6	0.126E+00
2. 3. 2	ROTOR	8	0.298E+00	44	0.335E-02	54	0.0	35	0.0
2. 3. 1	CAP	9	0.295E+00	43	0.335E-02	53	0.0	34	0.0
6. 9. 2	CAT ACTIVE MEDIA	10	0.190E+00	11	0.190E+00	122	0.0	119	0.0
6. 2. 1	EVAP CANISTER	11	0.147E+00	89	0.0	100	0.0	70	0.0
6.10. 1	HEAT RISER	12	0.143E+00	30	0.117E-01	125	0.0	122	0.0
2. 1. 0	POINTS	13	0.112E+00	60	0.393E-03	51	0.0	32	0.0
1. 3.10	IDLE ADJUSTMENT	14	0.810E-01	10	0.268E+00	48	0.0	29	0.0
3. 1. 3	TAC VAC MOTOR	15	0.725E-01	38	0.557E-02	68	0.0	51	0.0
3. 1. 4	TAC VAC HOSES	16	0.724E-01	39	0.555E-02	69	0.0	52	0.0
2. 7. 0	COIL	17	0.714E-01	49	0.201E-02	62	0.0	44	0.0
2. 9. 0	BALLAST RESISTOR	18	0.714E-01	51	0.200E-02	64	0.0	46	0.0
6. 1. 1	PCV VALVE	19	0.694E-01	9	0.309E+00	96	0.0	66	0.0
6. 1. 3	PCV FRSHAIR FLTR	20	0.627E-01	12	0.171E+00	98	0.0	68	0.0
6. 1. 2	PCV HOSES	21	0.538E-01	56	0.112E-02	97	0.0	67	0.0
6. 2. 2	EVAP HOSES	22	0.537E-01	57	0.112E-02	101	0.0	71	0.0
5. 1. 2	VALVE CAM LOBES	23	0.521E-01	15	0.521E-01	88	0.0	9	0.126E-01
5. 1. 3	VALVE GUIDES	24	0.521E-01	16	0.521E-01	89	0.0	10	0.126E-01
5. 2. 0	PISTON RINGS	25	0.521E-01	17	0.521E-01	92	0.0	11	0.126E-01

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - ALL MODELS

PRINCIPAL RANKING - HC (CONT'D)

PART CODE	PART NAME	HC		CO		NOX		SMOKE	
		RANK	CI	RANK	CI	RANK	CI	RANK	CI
6. 3. 7	AI PUMP/BELTS	26	0.433E-01	19	0.433E-01	112	0.0	82	0.0
6. 3. 2	AI HOSES	27	0.433E-01	14	0.670E-01	107	0.0	77	0.0
2. 3. 5	DISTRIBUTOR DRIV	28	0.396E-01	58	0.111E-02	57	0.0	38	0.0
6. 2. 3	EVAP FRSH AIR	29	0.357E-01	90	0.0	102	0.0	72	0.0
2. 4. 0	MAG/OPT TRIGGERS	30	0.312E-01	62	0.198E-03	59	0.0	41	0.0
1. 3. 3	VAC BRK VALVE	31	0.271E-01	13	0.858E-01	41	0.0	22	0.0
3. 1. 1	TAC SHROUD	32	0.268E-01	76	0.0	66	0.0	49	0.0
3. 1. 2	TAC THERMOSTAT	33	0.268E-01	77	0.0	67	0.0	50	0.0
1. 3. 5	ACCELERATOR PUMP	34	0.268E-01	23	0.268E-01	43	0.0	24	0.0
1. 3. 9	FLOAT AND VALVE	35	0.267E-01	4	0.535E+00	47	0.0	28	0.0
6. 2. 6	FUEL TANK/CAP	36	0.249E-01	93	0.0	105	0.0	75	0.0
6. 2. 4	EVAP VPRLIG SEP	37	0.238E-01	91	0.0	103	0.0	73	0.0
2. 3. 7	SPARK DELAY VLV	38	0.202E-01	72	0.0	3	0.202E+00	40	0.0
1. 4. 0	FUEL FILTER	39	0.191E-01	40	0.431E-02	50	0.0	31	0.0
1. 3. 2	METERING RODS	40	0.185E-01	7	0.370E+00	40	0.0	21	0.0
3. 2. 0	AIR CLEANER ELEM	41	0.167E-01	8	0.335E+00	71	0.0	8	0.140E-01
1. 3. 1	METERING JETS	42	0.163E-01	25	0.163E-01	39	0.0	20	0.0
6. 2. 5	EVAP VAPOR CONTR	43	0.135E-01	92	0.0	104	0.0	74	0.0
6. 3. 5	AI BYPASS/DVRTR	44	0.133E-01	22	0.302E-01	110	0.0	80	0.0
5. 4. 1	HEAD GASKETS	45	0.124E-01	29	0.124E-01	94	0.0	12	0.190E-02
6. 3. 4	AI CHECK VALVES	46	0.116E-01	31	0.116E-01	109	0.0	79	0.0
6. 3. 3	AI AIR FILTER	47	0.107E-01	34	0.107E-01	108	0.0	78	0.0
6. 3. 1	AI MANIFOLD	48	0.942E-02	27	0.144E-01	106	0.0	76	0.0
1. 2. 1	IDLE STPSOLENOID	49	0.938E-02	20	0.372E-01	36	0.0	17	0.0
1. 3. 7	GASKETS	50	0.886E-02	50	0.201E-02	45	0.0	26	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - ALL MODELS

PRINCIPAL RANKING - CO

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
1. 3. 4	CHOKE MECHANISM	4	0.531E+00	1	0.266E+01	42	0.0	23	0.0
1. 3. 6	POWER VALVES	5	0.531E+00	2	0.266E+01	44	0.0	25	0.0
5. 1. 1	VALVE LIFTER/SPR	3	0.873E+00	3	0.873E+00	87	0.0	2	0.211E+00
1. 3. 9	FLOAT AND VALVE	35	0.267E-01	4	0.535E+00	47	0.0	28	0.0
5. 1. 4	VALVE SEALS	6	0.521E+00	5	0.521E+00	90	0.0	5	0.126E+00
5. 1. 5	EXHAUST VALVES	7	0.521E+00	6	0.521E+00	91	0.0	6	0.126E+00
1. 3. 2	METERING RODS	40	0.185E-01	7	0.370E+00	40	0.0	21	0.0
3. 2. 0	AIR CLEANER ELEM	41	0.167E-01	8	0.335E+00	71	0.0	8	0.140E-01
6. 1. 1	PCV VALVE	19	0.694E-01	9	0.309E+00	96	0.0	66	0.0
1. 3.10	IDLE ADJUSTMENT	14	0.810E-01	10	0.268E+00	48	0.0	29	0.0
6. 9. 2	CAT ACTIVE MEDIA	10	0.190E+00	11	0.190E+00	122	0.0	119	0.0
6. 1. 3	PCV FRSHAIR FLTR	20	0.627E-01	12	0.171E+00	98	0.0	68	0.0
1. 3. 3	VAC BRK VALVE	31	0.271E-01	13	0.858E-01	41	0.0	22	0.0
6. 3. 2	AI HOSES	27	0.433E-01	14	0.670E-01	107	0.0	77	0.0
5. 1. 2	VALVE CAM LOBES	23	0.521E-01	15	0.521E-01	88	0.0	9	0.126E-01
5. 1. 3	VALVE GUIDES	24	0.521E-01	16	0.521E-01	89	0.0	10	0.126E-01
5. 2. 0	PISTON RINGS	25	0.521E-01	17	0.521E-01	92	0.0	11	0.126E-01
2. 3. 4	VACUUM ADVANCE	99	0.0	18	0.451E-01	56	0.0	37	0.0
6. 3. 7	AI PUMP/BELTS	26	0.433E-01	19	0.433E-01	112	0.0	82	0.0
1. 2. 1	IDLE STPSOLENOID	49	0.938E-02	20	0.372E-01	36	0.0	17	0.0
2. 5. 0	SPARK PLUGS	1	0.300E+02	21	0.348E-01	60	0.0	42	0.0
6. 3. 5	AI BYPASS/DVRTR	44	0.133E-01	22	0.302E-01	110	0.0	80	0.0
1. 3. 5	ACCELERATOR PUMP	34	0.268E-01	23	0.268E-01	43	0.0	24	0.0
2. 6. 0	IGNITION WIRES	2	0.107E+02	24	0.237E-01	61	0.0	43	0.0
1. 3. 1	METERING JETS	42	0.163E-01	25	0.163E-01	39	0.0	20	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - ALL MODELS

PRINCIPAL RANKING - CO (CONT'D)

PART CODE	PART NAME	HC		CO		NOX		SMOKE	
		RANK	CI	RANK	CI	RANK	CI	RANK	CI
2. 3. 3	MECH ADVANCE	98	0.0	26	0.150E-01	55	0.0	36	0.0
6. 3. 1	AI MANIFOLD	48	0.942E-02	27	0.144E-01	106	0.0	76	0.0
4.12. 0	FI STARTING VALV	62	0.284E-02	28	0.142E-01	85	0.0	64	0.0
5. 4. 1	HEAD GASKETS	45	0.124E-01	29	0.124E-01	94	0.0	12	0.190E-02
6.10. 1	HEAT RISER	12	0.143E+00	30	0.117E-01	125	0.0	122	0.0
6. 3. 4	AI CHECK VALVES	46	0.116E-01	31	0.116E-01	109	0.0	79	0.0
6.10. 4	DECEL VALVE	57	0.363E-02	32	0.113E-01	128	0.0	125	0.0
6.10. 2	ELEC ASSIST CHKE	65	0.262E-02	33	0.108E-01	126	0.0	123	0.0
6. 3. 3	AI AIR FILTER	47	0.107E-01	34	0.107E-01	108	0.0	78	0.0
4. 9. 0	EFI INJECTORS	81	0.360E-03	35	0.719E-02	83	0.0	61	0.0
5. 5. 0	CAMSHAFTS	51	0.714E-02	36	0.714E-02	95	0.0	13	0.190E-02
1. 2. 2	THROTTLE DASHPOT	73	0.674E-03	37	0.674E-02	37	0.0	18	0.0
3. 1. 3	TAC VAC MOTOR	15	0.725E-01	38	0.557E-02	68	0.0	51	0.0
3. 1. 4	TAC VAC HOSES	16	0.724E-01	39	0.555E-02	69	0.0	52	0.0
1. 4. 0	FUEL FILTER	39	0.191E-01	40	0.431E-02	50	0.0	31	0.0
6. 5. 4	TCS CEC VALVE	56	0.425E-02	41	0.425E-02	114	0.0	98	0.0
1. 2. 3	THRTTL POSITIONR	78	0.376E-03	42	0.376E-02	38	0.0	19	0.0
2. 3. 1	CAP	9	0.295E+00	43	0.335E-02	53	0.0	34	0.0
2. 3. 2	ROTOR	8	0.298E+00	44	0.335E-02	54	0.0	35	0.0
4.13. 0	FI IDLE ADJUST	63	0.283E-02	45	0.283E-02	86	0.0	4	0.126E+00
1. 3.11	IDLE ENRICHMENT	66	0.261E-02	46	0.261E-02	49	0.0	30	0.0
6. 5. 2	TCS VAC HOSES	69	0.165E-02	47	0.261E-02	113	0.0	96	0.0
2. 3. 6	DUAL DIAPHM DIST	100	0.0	48	0.212E-02	58	0.0	39	0.0
2. 7. 0	COIL	17	0.714E-01	49	0.201E-02	62	0.0	44	0.0
1. 3. 7	GASKETS	50	0.886E-02	50	0.201E-02	45	0.0	26	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - ALL MODELS

PRINCIPAL RANKING - NOX

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
6. 4. 1	EGR VALVES	115	0.0	95	0.0	1	0.729E+00	83	0.0
6. 4. 3	EGR THERMO VALVE	116	0.0	97	0.0	2	0.336E+00	85	0.0
2. 3. 7	SPARK DELAY VLV	38	0.202E-01	72	0.0	3	0.202E+00	40	0.0
6. 4. 8	EGR VAC AMP	54	0.588E-02	102	0.0	4	0.118E+00	90	0.0
6.10. 7	THERMO VAC VALV	55	0.545E-02	128	0.0	5	0.109E+00	128	0.0
6. 4. 2	EGR HOSES/SEALS	58	0.359E-02	96	0.0	6	0.719E-01	84	0.0
6. 5. 8	TCS TEMP SWITCH	59	0.348E-02	112	0.0	7	0.696E-01	102	0.0
2.11. 0	IGN TIMING ADJ	52	0.695E-02	75	0.0	8	0.695E-01	48	0.0
6. 5. 6	TCS TRANS SWITCH	61	0.297E-02	110	0.0	9	0.594E-01	100	0.0
6. 5. 1	TCS VAC SOLENOID	64	0.279E-02	107	0.0	10	0.559E-01	95	0.0
6. 4. 4	EGR SOLENOID VLV	117	0.0	98	0.0	11	0.479E-01	86	0.0
6. 5. 3	TCS TIME DELAY	67	0.189E-02	108	0.0	12	0.377E-01	97	0.0
6. 7. 1	DSAC VAC ORIFICE	60	0.309E-02	117	0.0	13	0.309E-01	108	0.0
6. 4.10	EGR CARB SPACER	122	0.0	104	0.0	14	0.297E-01	92	0.0
6. 4.11	EGR BACKPRES SEN	123	0.0	105	0.0	15	0.293E-01	93	0.0
6. 5. 5	TCS THERMO VALVE	71	0.128E-02	109	0.0	16	0.257E-01	99	0.0
6. 4. 7	EGR TIME DELAY	120	0.0	101	0.0	17	0.240E-01	89	0.0
6. 4. 5	EGR TEMP SWITCH	118	0.0	99	0.0	18	0.236E-01	87	0.0
6. 4. 6	EGR SPEED/TRANS	119	0.0	100	0.0	19	0.190E-01	88	0.0
6. 7. 4	DSAC VAC BYPASS	70	0.130E-02	119	0.0	20	0.130E-01	111	0.0
6. 8. 5	ESC SPEED SWITCH	74	0.621E-03	124	0.0	21	0.124E-01	117	0.0
6. 8. 1	ESC ELEC MODULE	77	0.431E-03	121	0.0	22	0.862E-02	113	0.0
6. 8. 3	ESC VAC VALVES	79	0.360E-03	122	0.0	23	0.719E-02	115	0.0
6. 8. 4	ESC TEMP SWITCH	80	0.360E-03	123	0.0	24	0.719E-02	116	0.0
6.10. 5	DIST VACDECL VLV	82	0.254E-03	127	0.0	25	0.508E-02	126	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - ALL MODELS

PRINCIPAL RANKING - NOX (CONT'D)

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
6. 6. 1	SCS VACUUM SOLEN	84	0.223E-03	113	0.0	26	0.447E-02	103	0.0
6. 6. 4	SCS SPEED SWITCH	85	0.223E-03	115	0.0	27	0.447E-02	106	0.0
6. 7. 5	OSAC TEMP SENSOR	76	0.432E-03	120	0.0	28	0.432E-02	112	0.0
6. 6. 5	SCS THERMO VALVE	86	0.212E-03	116	0.0	29	0.423E-02	107	0.0
6. 4. 9	EGR VAC REDUCER	121	0.0	103	0.0	30	0.181E-02	91	0.0
6. 4.12	EGR CHECK VALVE	124	0.0	106	0.0	31	0.316E-03	94	0.0
8. 1. 0	DISTR VACUUM VLV	92	0.430E-04	133	0.0	32	0.430E-04	133	0.0
4.10. 0	EFI TRIGGER SWCH	93	0.273E-04	68	0.137E-04	33	0.137E-05	62	0.0
1. 1. 1	NEW CARB	95	0.0	69	0.0	34	0.0	15	0.0
1. 1. 2	REBUILT CARB	96	0.0	70	0.0	35	0.0	16	0.0
1. 2. 1	IDLE STPSOLENOID	49	0.938E-02	20	0.372E-01	36	0.0	17	0.0
1. 2. 2	THROTTLE DASHPOT	73	0.674E-03	37	0.674E-02	37	0.0	18	0.0
1. 2. 3	THRTTL POSITIONR	78	0.376E-03	42	0.376E-02	38	0.0	19	0.0
1. 3. 1	METERING JETS	42	0.163E-01	25	0.163E-01	39	0.0	20	0.0
1. 3. 2	METERING RODS	40	0.185E-01	7	0.370E+00	40	0.0	21	0.0
1. 3. 3	VAC BRK VALVE	31	0.271E-01	13	0.858E-01	41	0.0	22	0.0
1. 3. 4	CHOKE MECHANISM	4	0.531E+00	1	0.266E+01	42	0.0	23	0.0
1. 3. 5	ACCELERATOR PUMP	34	0.268E-01	23	0.268E-01	43	0.0	24	0.0
1. 3. 6	POWER VALVES	5	0.531E+00	2	0.266E+01	44	0.0	25	0.0
1. 3. 7	GASKETS	50	0.886E-02	50	0.201E-02	45	0.0	26	0.0
1. 3. 8	REBUILDING KITS	97	0.0	71	0.0	46	0.0	27	0.0
1. 3. 9	FLOAT AND VALVE	35	0.267E-01	4	0.535E+00	47	0.0	28	0.0
1. 3.10	IDLE ADJUSTMENT	14	0.810E-01	10	0.268E+00	48	0.0	29	0.0
1. 3.11	IDLE ENRICHMENT	66	0.261E-02	46	0.261E-02	49	0.0	30	0.0
1. 4. 0	FUEL FILTER	39	0.191E-01	40	0.431E-02	50	0.0	31	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - ALL MODELS

PRINCIPAL RANKING - SMOKE

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
4. 5. 0	MFI VALVES	109	0.0	84	0.0	79	0.0	1	0.253E+01
5. 1. 1	VALVE LIFTER/SPR	3	0.873E+00	3	0.873E+00	87	0.0	2	0.211E+00
4. 4. 0	FI THROTTLE VALV	108	0.0	83	0.0	78	0.0	3	0.129E+00
4.13. 0	FI IDLE ADJUST	63	0.283E-02	45	0.283E-02	86	0.0	4	0.126E+00
5. 1. 4	VALVE SEALS	6	0.521E+00	5	0.521E+00	90	0.0	5	0.126E+00
5. 1. 5	EXHAUST VALVES	7	0.521E+00	6	0.521E+00	91	0.0	6	0.126E+00
4. 3. 0	FI PRES SENS/REG	90	0.170E-03	54	0.170E-02	77	0.0	7	0.398E-01
3. 2. 0	AIR CLEANER ELEM	41	0.167E-01	8	0.335E+00	71	0.0	8	0.140E-01
5. 1. 2	VALVE CAM LOBES	23	0.521E-01	15	0.521E-01	88	0.0	9	0.126E-01
5. 1. 3	VALVE GUIDES	24	0.521E-01	16	0.521E-01	89	0.0	10	0.126E-01
5. 2. 0	PISTON RINGS	25	0.521E-01	17	0.521E-01	92	0.0	11	0.126E-01
5. 4. 1	HEAD GASKETS	45	0.124E-01	29	0.124E-01	94	0.0	12	0.190E-02
5. 5. 0	CAMSHAFTS	51	0.714E-02	36	0.714E-02	95	0.0	13	0.190E-02
3. 4. 0	TURBOCHARGER	104	0.0	79	0.0	73	0.0	14	0.187E-03
1. 1. 1	NEW CARB	95	0.0	69	0.0	34	0.0	15	0.0
1. 1. 2	REBUILT CARB	96	0.0	70	0.0	35	0.0	16	0.0
1. 2. 1	IDLE STPSOLENOID	49	0.938E-02	20	0.372E-01	36	0.0	17	0.0
1. 2. 2	THROTTLE DASHPOT	73	0.674E-03	37	0.674E-02	37	0.0	18	0.0
1. 2. 3	THRTTL POSITIONR	78	0.376E-03	42	0.376E-02	38	0.0	19	0.0
1. 3. 1	METERING JETS	42	0.163E-01	25	0.163E-01	39	0.0	20	0.0
1. 3. 2	METERING RODS	40	0.185E-01	7	0.370E+00	40	0.0	21	0.0
1. 3. 3	VAC BRK VALVE	31	0.271E-01	13	0.858E-01	41	0.0	22	0.0
1. 3. 4	CHOKE MECHANISM	4	0.531E+00	1	0.266E+01	42	0.0	23	0.0
1. 3. 5	ACCELERATOR PUMP	34	0.266E-01	23	0.268E-01	43	0.0	24	0.0
1. 3. 6	POWER VALVES	5	0.531E+00	2	0.266E+01	44	0.0	25	0.0

AUTOMOTIVE PARTS STUDY - EPA CONTRACT NO. 68-01-1957

CRITICALITY INDEX RANKING - ALL MODELS

PRINCIPAL RANKING - SMOKE (CONT'D)

PART CODE	PART NAME	HC RANK	HC CI	CO RANK	CO CI	NOX RANK	NOX CI	SMOKE RANK	SMOKE CI
1. 3. 7	GASKETS	50	0.886E-02	50	0.201E-02	45	0.0	26	0.0
1. 3. 8	REBUILDING KITS	97	0.0	71	0.0	46	0.0	27	0.0
1. 3. 9	FLOAT AND VALVE	35	0.267E-01	4	0.535E+00	47	0.0	28	0.0
1. 3.10	IDLE ADJUSTMENT	14	0.810E-01	10	0.268E+00	48	0.0	29	0.0
1. 3.11	IDLE ENRICHMENT	66	0.261E-02	46	0.261E-02	49	0.0	30	0.0
1. 4. 0	FUEL FILTER	39	0.191E-01	40	0.431E-02	50	0.0	31	0.0
2. 1. 0	POINTS	13	0.112E+00	60	0.393E-03	51	0.0	32	0.0
2. 2. 0	CONDENSER	53	0.658E-02	67	0.168E-04	52	0.0	33	0.0
2. 3. 1	CAP	9	0.295E+00	43	0.335E-02	53	0.0	34	0.0
2. 3. 2	ROTOR	8	0.298E+00	44	0.335E-02	54	0.0	35	0.0
2. 3. 3	MECH ADVANCE	98	0.0	26	0.150E-01	55	0.0	36	0.0
2. 3. 4	VACUUM ADVANCE	99	0.0	18	0.451E-01	56	0.0	37	0.0
2. 3. 5	DISTRIBUTOR DRIV	28	0.376E-01	58	0.111E-02	57	0.0	38	0.0
2. 3. 6	DUAL DIAPHM DIST	100	0.0	48	0.212E-02	58	0.0	39	0.0
2. 3. 7	SPARK DELAY VLV	38	0.202E-01	72	0.0	3	0.202E+00	40	0.0
2. 4. 0	MAG/OPT TRIGGERS	30	0.312E-01	62	0.198E-03	59	0.0	41	0.0
2. 5. 0	SPARK PLUGS	1	0.300E+02	21	0.348E-01	60	0.0	42	0.0
2. 6. 0	IGNITION WIRES	2	0.107E+02	24	0.237E-01	61	0.0	43	0.0
2. 7. 0	COIL	17	0.714E-01	49	0.201E-02	62	0.0	44	0.0
2. 8. 0	CAPACITIVE DISCH	101	0.0	73	0.0	63	0.0	45	0.0
2. 9. 0	BALLAST RESISTOR	18	0.714E-01	51	0.200E-02	64	0.0	46	0.0
2.10. 0	EI CONTROL CIRCT	102	0.0	74	0.0	65	0.0	47	0.0
2.11. 0	IGN TIMING ADJ	52	0.695E-02	75	0.0	8	0.695E-01	48	0.0
3. 1. 1	TAC SHROUD	32	0.268E-01	76	0.0	66	0.0	49	0.0
3. 1. 2	TAC THERMOSTAT	33	0.268E-01	77	0.0	67	0.0	50	0.0

Appendix B

CRITICALITY INDEX INPUT PARAMETER VALUES

PART NAME	EMISSION INCREASE FACTORS — GASOLINE — PRE-1975 EVAP	HC	CO	NOX	POST-1975 HC	CO	NOX	DIESEL(SMOKE) PRE-1974 ACCEL	LUG	POST-1974 ACCEL	LUG	PEAK	PROBABILITY FACTORS EARLY FAIL	NO REPL	VOLUME FACTORS 72-74	75
NEW CARB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.77077	0.22290
REBUILT CARB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.76920	0.22290
IDLE STPSOLENOID	0.0	0.1	1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.61724	0.12593
THROTTLE DASHPOT	0.0	0.1	1.0	0.0	0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.05548	0.07926
THRTTL POSITIONR	0.0	0.1	1.0	0.0	0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.04121	0.03392
METERING JETS	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	1.39934	0.41207
METERING RODS	0.0	0.1	2.0	0.0	0.1	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.41995	0.26506
VAC BRK VALVE	0.0	0.1	0.1	0.0	0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.76110	0.24175
CHOKE MECHANISM	0.0	2.0	10.0	0.0	2.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.76110	0.22290
ACCELERATOR PUMP	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.76110	0.23081
POWER VALVES	0.0	2.0	10.0	0.0	2.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.76110	0.22290
GASKETS	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.76110	0.22290
REBUILDING KITS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.76738	0.22290
FLOAT AND VALVE	0.0	0.1	2.0	0.0	0.1	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.76738	0.22290
IDLE ADJUSTMENT	0.0	0.1	1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.90	0.30	0.77077	0.22290
IDLE ENRICHMENT	0.0	0.1	1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.0	0.02905
FUEL FILTER	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	2.94968	0.86294
POINTS	0.0	1.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.50	0.10	2.23211	0.07656
CONDENSER	0.0	1.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.10	0.65669	0.01679
CAP	0.0	2.0	0.0	0.0	2.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.50	0.75877	0.22336
ROTOR	0.0	2.0	0.0	0.0	2.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.50	0.77077	0.22336
MECH ADVANCE	0.0	0.0	0.1	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.77077	0.22336
VACUUM ADVANCE	0.0	0.0	0.1	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.50	0.77077	0.22336
DISTRIBUTOR DRIV	0.0	1.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.77077	0.22228
DUAL DIAPHM DIST	0.0	0.0	0.1	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.05245	0.00256
SPARK DELAY VLV	0.0	0.1	0.0	1.0	0.1	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.50	0.90	0.38332	0.06637
MAG/OPT TRIGGERS	0.0	10.0	0.0	0.0	10.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.10	0.11409	0.19785
SPARK PLUGS	0.0	10.0	0.0	0.0	10.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.70	0.10	37.86034	4.96785
IGNITION WIRES	0.0	10.0	0.0	0.0	10.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.50	5.58569	1.57853
COIL	0.0	1.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.77077	0.22336
CAPACITIVE DISCH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
BALLAST RESISTOR	0.0	1.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.77077	0.22197
EI CONTROL CIRCT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.11409	0.20848
IGN TIMING ADJ	0.0	0.1	0.0	1.0	0.1	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.70	0.10	0.77077	0.22228
TAC SHROUD	0.0	0.1	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.74813	0.22336
TAC THERMOSTAT	0.0	0.1	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.74813	0.22336

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PART NAME	EMISSION INCREASE FACTORS												PROBABILITY FACTORS		VOLUME FACTORS	
	GASOLINE							DIESEL(SMOKE)								
		PRE-1975			POST-1975			PRE-1974		POST-1974						
	EVAP	HC	CO	NOX	HC	CO	NOX	ACCEL	LUG	ACCEL	LUG	PEAK	EARLY FAIL	NO REPL	72-74	75
TAC VAC MOTOR	0.0	0.1	0.0	0.0	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.62497	0.20613
TAC VAC HOSES	0.0	0.1	0.0	0.0	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.62443	0.20568
TAC FRESH AIR IN	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.0	0.00723
AIR CLEANER ELEM	0.0	0.1	2.0	0.0	0.1	2.0	0.0	1.0	0.0	1.0	0.0	1.0	0.10	0.50	2.88371	0.46598
INTAKE MANIFOLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.77077	0.22793
TURBOCHARGER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.1	1.0	0.1	1.0	0.10	0.30	0.0	0.00223
SUPERCHARGER	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MFI ACCUMULATOR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.01	0.90	0.0	0.0
FI HI PRES PUMP	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00676
FI PRES SENS/REG	0.0	0.1	1.0	0.0	0.1	1.0	0.0	1.0	0.1	1.0	0.1	1.0	0.30	0.90	0.0	0.00630
FI THROTTLE VALV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.1	2.0	0.1	2.0	0.50	0.90	0.0	0.00630
MFI VALVES	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	2.00	0.90	0.0	0.03933
EFI AIR SENS/SWH	0.0	1.0	5.0	0.0	1.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.10	0.0	0.00046
EFI TEMPSENS/SWH	0.0	1.0	5.0	0.0	1.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.0	0.00091
FI DIST MANIFOLD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00630
EFI INJECTORS	0.0	0.1	2.0	0.0	0.1	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.50	0.90	0.0	0.00799
EFI TRIGGER SWCH	0.0	2.0	0.1	0.1	2.0	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.30	0.10	0.0	0.00046
EFI CONTROL CIRC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00046
FI STARTING VALV	0.0	1.0	5.0	0.0	1.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.50	0.90	0.0	0.00630
FI IDLE ADJUST	0.0	0.1	1.0	0.0	1.0	1.0	0.0	1.0	1.0	1.0	1.0	2.0	0.50	0.30	0.0	0.01889
VALVE LIFTER/SPR	0.0	1.0	1.0	0.0	0.1	0.1	0.0	1.0	1.0	1.0	1.0	1.0	0.30	0.50	5.63017	1.86923
VALVE CAM LUBES	0.0	1.0	1.0	0.0	0.1	0.1	0.0	1.0	1.0	1.0	1.0	1.0	0.01	0.90	5.63017	1.61785
VALVE GUIDES	0.0	1.0	1.0	0.0	0.1	0.1	0.0	1.0	1.0	1.0	1.0	1.0	0.01	0.90	5.63017	1.61785
VALVE SEALS	0.0	1.0	1.0	0.0	0.1	0.1	0.0	1.0	1.0	1.0	1.0	1.0	0.10	0.90	5.63017	1.61785
EXHAUST VALVES	0.0	1.0	1.0	0.0	0.1	0.1	0.0	1.0	1.0	1.0	1.0	1.0	0.10	0.90	5.63017	1.61785
PISTON RINGS	0.0	1.0	1.0	0.0	0.1	0.1	0.0	1.0	1.0	1.0	1.0	1.0	0.01	0.90	5.63017	1.61785
PISTON/RODS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.63017	1.61785
HEAD GASKETS	0.0	1.0	1.0	0.0	0.1	0.1	0.0	1.0	1.0	1.0	1.0	1.0	0.01	0.90	1.33921	0.38741
CAMSHAFTS	0.0	1.0	1.0	0.0	0.1	0.1	0.0	1.0	1.0	1.0	1.0	1.0	0.01	0.90	0.77077	0.22971
PCV VALVE	0.0	0.1	1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.30	2.95964	0.47485
PCV HOSES	10.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.77077	0.22336
PCV FRSHAIR FLTR	0.0	0.1	1.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.70	1.71585	0.72344
PCV OIL SEPARATR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00055	0.01892
EVAP CANISTER	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.30	0.50	0.79021	0.22336
EVAP HOSES	10.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.76970	0.22336
EVAP FRSH AIR	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	2.19215	0.52220

	EMISSION INCREASE FACTORS												PROBABILITY FACTORS		VOLUME FACTORS	
	GASOLINE							DIESEL(SMOKE)								
PART NAME		PRE-1975			POST-1975			PRE-1974		POST-1974			EARLY	NO		
	EVAP	HC	CO	NOX	HC	CO	NOX	ACCEL	LUG	ACCEL	LUG	PEAK	FAIL	REPL	72-74	75
EVAP VPRLIG SEP	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.75531	0.20814
EVAP VAPOR CONTR	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.36345	0.13376
FUEL TANK/CAP	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.76706	0.22336
AI MANIFOLD	0.0	1.0	1.0	0.0	2.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01	0.90	0.67442	0.18592
AI HOSES	0.0	1.0	1.0	0.0	2.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.70	0.39273	0.11275
AI AIR FILTER	0.0	0.1	0.1	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.70	0.39667	0.11309
AI CHECK VALVES	0.0	0.1	0.1	0.0	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.66629	0.16547
AI BYPASS/DVRTR	0.0	0.1	0.1	0.0	2.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.39273	0.11309
AI GULP VALVES	0.0	0.1	0.1	0.0	2.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.0	0.0
AI PUMP/BELTS	0.0	1.0	1.0	0.0	2.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.70	0.39273	0.11309
EGR VALVES	0.0	0.0	0.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.70	0.70	0.52799	0.21629
EGR HOSES/SEALS	0.0	0.1	0.0	2.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.50239	0.21629
EGR THERMO VALVE	0.0	0.0	0.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.37807	0.24450
EGR SOLENOID VLV	0.0	0.0	0.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.23601	0.02988
EGR TEMP SWITCH	0.0	0.0	0.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.13025	0.00084
EGR SPEED/TRANS	0.0	0.0	0.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.04878	0.05654
EGR TIME DELAY	0.0	0.0	0.0	2.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.10445	0.02905
EGR VAC AMP	0.0	0.1	0.0	2.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.13292	0.08475
EGR VAC REDUCER	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.00672	0.0
EGR CARB SPACER	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.05342	0.05655
EGR BACKPRES SEN	0.0	0.0	0.0	1.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.70	0.90	0.02277	0.02371
EGR CHECK VALVE	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.01172	0.0
TCS VAC SOLENOID	0.0	0.1	0.0	2.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.28903	0.02137
TCS VAC HOSES	0.0	0.1	0.1	0.0	0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.30840	0.02137
TCS TIME DELAY	0.0	0.1	0.0	2.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.20296	0.00657
TCS CEC VALVE	0.0	2.0	2.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.02364	0.0
TCS THERMO VALVE	0.0	0.1	0.0	2.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.04054	0.00699
TCS TRANS SWITCH	0.0	0.1	0.0	2.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.30840	0.02137
TCS REVERSE RELY	0.0	0.1	0.0	2.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.0	0.0
TCS TEMP SWITCH	0.0	0.1	0.0	2.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.36325	0.02320
SCS VACUUM SOLEN	0.0	0.1	0.0	2.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.02399	0.00084
SCS VACUM LINE	0.0	0.1	0.1	0.0	0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10	0.50	0.02399	0.00084
SCS TIME DELAY	0.0	0.1	0.0	2.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.0	0.0
SCS SPEED SWITCH	0.0	0.1	0.0	2.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.10	0.90	0.02399	0.00084
SCS THERMO VALVE	0.0	0.1	0.0	2.0	0.1	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.00701	0.00084
OSAC VAC ORIFICE	0.0	0.1	0.0	1.0	0.1	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.30	0.90	0.08529	0.02905

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                                             EMISSION INCREASE FACTORS                             PROBABILITY
                     --------------- GASOLINE ---------------    ------- DIESEL(SMOKE) -------      FACTORS     VOLUME
   PART                   -- PRE-1975 --     -- POST-1975 --     PRE-1974    --- POST-1974 ---  EARLY   NO      FACTORS
   NAME            EVAP  HC    CO    NOX   HC    CO    NOX   ACCEL  LUG   ACCEL  LUG   PEAK   FAIL  REPL  72-74    75

 OSAC VAC HOSES     0.0  0.1   0.1   0.0   0.1   1.0   0.0   0.0    0.0   0.0    0.0   0.0    0.10  0.50 0.08529 0.02905
 OSAC THERMO VALV   0.0  0.1   0.0   1.0   0.1   0.0   1.0   0.0    0.0   0.0    0.0   0.0    0.30  0.90 0.0     0.0
 OSAC VAC BYPASS    0.0  0.1   0.0   1.0   0.1   0.0   1.0   0.0    0.0   0.0    0.0   0.0    0.30  0.90 0.04801 0.0
 OSAC TEMP SENSOR   0.0  0.1   0.0   1.0   0.1   0.0   1.0   0.0    0.0   0.0    0.0   0.0    0.10  0.90 0.04801 0.0
 ESC ELEC MODULE    0.0  0.1   0.0   2.0   0.1   0.0   2.0   0.0    0.0   0.0    0.0   0.0    0.10  0.90 0.03996 0.00791
 ESC HOSES          0.0  0.1   0.1   0.0   0.1   1.0   0.0   0.0    0.0   0.0    0.0   0.0    0.10  0.50 0.03996 0.0
 ESC VAC VALVES     0.0  0.1   0.0   2.0   0.1   0.0   2.0   0.0    0.0   0.0    0.0   0.0    0.10  0.90 0.03996 0.0
 ESC TEMP SWITCH    0.0  0.1   0.0   2.0   0.1   0.0   2.0   0.0    0.0   0.0    0.0   0.0    0.10  0.90 0.03996 0.0
 ESC SPEED SWITCH   0.0  0.1   0.0   2.0   0.1   0.0   2.0   0.0    0.0   0.0    0.0   0.0    0.10  0.90 0.03996 0.02905
 CAT BODY           0.0  0.0   0.0   0.0   0.1   0.1   0.0   0.0    0.0   0.0    0.0   0.0    0.01  0.90 0.0     0.21114
 CAT ACTIVE MEDIA   0.0  0.0   0.0   0.0   2.0   2.0   0.0   0.0    0.0   0.0    0.0   0.0    0.50  0.90 0.0     0.21114
 CAT INERTMEDIA     0.0  0.0   0.0   0.0   0.0   0.0   0.0   0.0    0.0   0.0    0.0   0.0    0.0   0.0  0.0     0.21114
 CAT SHELL          0.0  0.0   0.0   0.0   0.0   0.0   0.0   0.0    0.0   0.0    0.0   0.0    0.0   0.0  0.0     0.21114
 HEAT RISER         0.0  0.1   0.0   0.0   1.0   0.1   0.0   0.0    0.0   0.0    0.0   0.0    0.70  0.90 0.41057 0.18552
 ELEC ASSIST CHKE   0.0  0.1   0.1   0.0   0.1   1.0   0.0   0.0    0.0   0.0    0.0   0.0    0.10  0.90 0.14015 0.10046
 STAGED PULLDOWN    0.0  0.1   0.1   0.0   0.1   1.0   0.0   0.0    0.0   0.0    0.0   0.0    0.30  0.90 0.06349 0.0
 DECEL VALVE        0.0  0.1   1.0   0.0   1.0   1.0   0.0   0.0    0.0   0.0    0.0   0.0    0.30  0.90 0.03164 0.01028
 DIST VACDECL VLV   0.0  0.1   0.0   2.0   0.1   0.0   2.0   0.0    0.0   0.0    0.0   0.0    0.30  0.90 0.00941 0.0
 DIST START SOLEN   0.0  1.0   1.0   0.0   1.0   1.0   0.0   0.0    0.0   0.0    0.0   0.0    0.10  0.50 0.01556 0.00359
 THERMO VAC VALV    0.0  0.1   0.0   2.0   0.1   0.0   2.0   0.0    0.0   0.0    0.0   0.0    0.30  0.90 0.08051 0.12116
 COOLING THERMST    0.0  0.0   0.0   0.0   0.0   0.0   0.0   0.0    0.0   0.0    0.0   0.0    0.0   0.0  0.76763 0.22921
 ELECTRICAL SYSTM   0.0  0.0   0.0   0.0   0.0   0.0   0.0   0.0    0.0   0.0    0.0   0.0    0.0   0.0  0.77077 0.22921
 HIGH PERF EXHAST   0.0  0.0   0.0   0.0   0.0   0.0   0.0   0.0    0.0   0.0    0.0   0.0    0.0   0.0  0.04425 0.0
 EXHAUST MANIFOLD   0.0  0.0   0.0   0.0   0.0   0.0   0.0   0.0    0.0   0.0    0.0   0.0    0.0   0.0  1.33921 0.38735
 DISTR VACUUM VLV   0.0  0.1   0.0   0.1   0.1   0.0   0.1   0.0    0.0   0.0    0.0   0.0    0.30  0.90 0.00159 0.0
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